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Observations on the Relationship of Engineering and Science*

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ENGINEERING is one of the most ancient of the practical arts which, after close to 50 centuries of progress and accomplishment as such, has, within the last century, been greatly strengthened and increased in scope and power through the "reduction to a science" of many of its methods and processes. Indeed, such a close integration between science and engineering has been achieved in recent years that the assumption is frequently made that it has always been thus and that engineering is, in fact, merely commercialized science. Yet only one branch of modern engineering may be said to have been born of scientific discovery, namely, electrical; civil engineering is as old as civilization, chemical engineering had its origins in the industrial arts of the ancients, mining and metallurgy are equally old as practical arts, and mechanical engineering owes its birth to men who had no claim to scientific knowledge. Actually the present close liaison between the intelligent "doers" and those who devote their intellectual activities to the search for answers to the question "how" has not been achieved without a struggle; and it was this struggle, between those who professed the practical ability to do and those who developed the scientific capacity to understand, that was resolved during the nineteenth century. It is our purpose briefly to review this development, and to comment on some of its implications.

In the first place, it must be understood that progress in engineering is not measured by the scope or completeness of technical knowledge—whether practical, empirical or scientific—nor by the location of the frontiers of research or discovery, but by the actual state and accomplishment of the engineering of the day, by works completed and in service "for the use and convenience of man." There is almost always a long lag between discovery and application. Many factors, mainly economic, exercise controls over application and use, which are quite as important as is discovery. There have been, for example, through the ages, four major factors which have thus limited or conditioned constructional activities in any period: the availability of materials; the availability of power—human, animal or mechanical; the extent of technical knowledge; and last, but far from least, economic and social demand.

Historians refer to the Bronze Age in an incredibly remote past, but the Age of Metal is comparatively recent—it is largely a product of the nineteenth century. The first cast-iron bridge was built at Coalbrookdale in western England in 1776. The first all-steel bridge in the United States was opened over the Missouri River at Glasgow in 1879. Earlier ages built in wood and stone. Metal was too costly for use other than in weapons, tools and fastenings.

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Only in an indirect and remote way did science play a part in this development. The coal-iron process, then Cort's puddling process for the production of wrought iron, Bessemer's converter, and the open-hearth process of Siemens which gave us steel, were not the product of the scientific laboratory but, like practically all earlier metallurgical advances, the discoveries of practical workers—men who followed the old trial-and-error method and devoted their lives to uncovering processes that were often based on actions which they were unable to explain.

While we still lack a complete understanding of many of these processes, scientific research has, of course, done much to explain them and thus to make improvements possible. It is, in fact, as a way to understanding, an instrument of rationalization, a means of improving methods and processes, rather than as a source of invention and discovery, that science, as we shall presently note, has made its major contribution to the progress of engineering.

It is also true that, in recent years, science has uncovered new metals and plastics which are of vital importance today and will undoubtedly be of greater importance in the future. But—to name one—aluminum, although this valuable metal was discovered by Wöhler in 1828, has only recently, after the lapse of almost a century, become available as an engineering material. Why the long delay between discovery and utilization?

The engineer, unfortunately, must cut his cloth in accordance with economic laws. The basic relationship in the utilization of new materials is quality *versus* cost—and this is a far from simple relationship. Qualities not only vary among different materials but these qualities have different values under different conditions, values that are often very difficult to evaluate. First costs not only vary with production methods and volume but depend upon use, fabrication and market. Some factors in this relationship are well illustrated by the present situation in the structural use of the alloy steels.

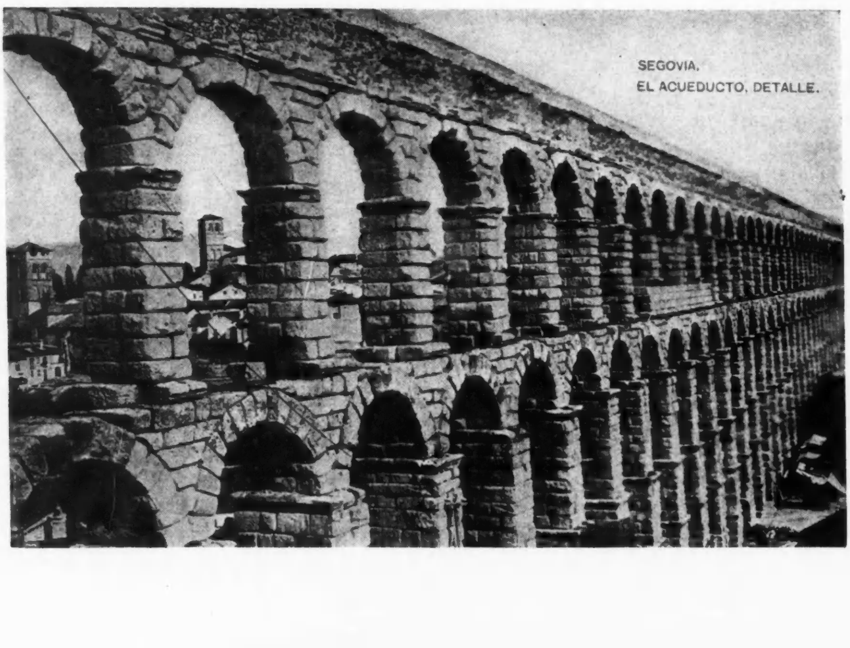
Many alloy steels are far stronger than the ordinary "structural grade" carbon steel, but they are also more costly per unit of strength. Unless, therefore, other values, other qualities than strength, can be realized through their use, the structural engineer must perforce stick to carbon steel. Yet the use of a high strength steel not only reduces the necessary size of the individual members of a structure such as a bridge but this, in turn, results in a decrease in weight and thus in the reduction of one of the major factors that determine the load for which a member must be designed—the "dead-load stresses." Now, as bridge spans are increased, the dead load increases more rapidly than the span. The point is reached, therefore, when this, so to speak, double saving in metal overbalances the added cost of alloy steel and it thus becomes an economical material. For large structures alloy steels have, accordingly, come into use, for it is also fortunately possible, where large tonnages are involved, for the steel producer to change over temporarily from his usual carbon output and produce and roll the required shapes—*I* beams, channels, and so forth—in alloy steel. Similar factors condition the adoption and practical use of any new material.

Other examples can also be cited of the abandonment of old materials—stone masonry and brick work, for example—owing to the development of new materials—cement and concrete—which permit mass construction methods. Discovery is, thus, but the first step and is usually followed by a long period of process development which may be retarded by lack of economic demand before a use is found for the new material. If the modern highway era had not led to the demand for long-span bridges, structural alloy steels would still be "on the shelf" awaiting the arrival of conditions permitting their use.

Changes in the second factor mentioned as conditioning the progress of construction—power—also casts some interesting light on the development of science and engineering. The "great man theory" of history seems to have captured the public imagination in recent years, and it is supposed to be possible to write the story of many branches of human endeavor by giving the biographies of a few leaders. While this may be true in the realm of art, literature and ideas, it is far from true in science and engineering. Science, we know, is an intelligent, organized search of Nature, and what we call modern science is the accumulation of many observations

Above, the Pont du Gard, an aqueduct bridge built about the beginning of the Christian era. Solid, heavy and massive, one of the most impressive of Roman ruins.

Below, the Aqueduct of Segovia, Spain, built about a century later under Trajan. A daring light framework of stone supporting at the top, as at Nimes, the small, built-in water conduit. Illustrating a remarkable structural advance based entirely on knowledge gained through experience. Neither work was the result of scientific analysis or well-rationalized design.



by many men. The modern technic and practice of engineering rests, similarly, on the accumulated knowledge, constantly sorted and sifted to eliminate dross, that has been built up over the centuries. It is from this capacity for continued growth and development, in the fact that many workers can, ant-like, add new grains of knowledge to the structure of science and engineering, that their tremendous power and promise of continued progress stem.

In the popular mind but one name is recalled when steam power is mentioned; Watt is popularly known as the inventor of the Steam Engine. As a matter of fact, back of Watt was Newcomen, with Savery back of Newcomen, and back of these a host of men from Hero of Alexandria to Dennis Papin who played with the idea of power from steam. Savery probably deserves the title of Father of the Steam Engine, but his engine was neither automatic nor economically practicable. A pit boy, tiring of the task of opening and closing valves to control the strokes of the Newcomen engine (actually a mine pump), rigged up some levers which made its functioning automatic. Watt made it economically practicable by devising the separate condenser which effected a tremendous saving in fuel. The name of those who have played a part in the evolution of this one basic device by addition and refinement, by applying it to new uses and adapting it to varying conditions and services, is *legion*. A similar statement would hold for almost all of the great fundamental devices on which our present-day civilization rests—they are not the sudden products of invention but the results of long drawn out and patient toil and evolution. Faraday can, I suppose, be credited with the basic discovery on which the electric dynamo depends, but it took at least 50 men and 50 years to develop from his discovery a practical, useful dynamo-electric machine.

The story of the steam engine also illustrates another basic fact—use very often has preceded understanding. The Greeks, for example, organized and systematized earlier empirical rules discovered by the Egyptians and created geometry—the science of land measurement. The lever was known and used for centuries before Archimedes discovered its basic law. And this is true of progress in some fields even today. Yet many historians of science state that Watt's improvement of the steam engine was a direct result of the discovery of the phenomena of latent heat by his friend, Joseph Black, a pioneer "heat philosopher." We are assured, however, by no less an authority than Watt himself that this was not the case. "I never did or could," wrote Watt, "consider my improvements as originating in these communications." Indeed, Watt's engine was a factor in exploding the old caloric theory of heat and in stimulating the development of the modern science of thermodynamics. The pioneer work of Sadi Carnot was not published until 1824 and Joule's work on the mechanical equivalent of heat did not follow until 1843–50. These basic contributions were, in fact, buried in little-known scientific papers, and it was Rankine, in his *Manual of the Steam Engine*, published in 1859, who

> ". . . to advantage dress'd
> What oft was thought, but ne'er so well express'd,"

thus making possible the translation of science into practice.

Fortunately, the modern situation, as my friend Professor T. T. Read has remarked, is one in which there is an integration of the practical capacity to do with the intellectual capacity to understand. Yet we should not lose sight of the fact that engineering cannot always wait for a full understanding—the engineer *must* find some practicable solution of the problems with which he is faced. Indeed, the successful engineer is said to be the man who, with insufficient evidence, guesses correctly nine times out of ten. Experience must, in some cases, continue to precede explanation.

One of the most impressive lessons of engineering history but confirms the statement that lack of technical and scientific knowledge has not prevented man from achieving great and useful works. The Roman bridge and aqueduct builder knew nothing of stresses and strains and force polygons. One seeks in vain among Perronet's writings for any deeper understanding of arch action than is represented by a purely qualitative knowledge of the fact that the compression in a voussoir arch of low rise was high and the horizontal component of the end thrust heavy.

Yet Perronet built a bridge that could not be improved upon by the most skilled modern designer working under similar limitations of form and materials—the Pont de la Concorde at Paris completed in 1793. The most striking demonstration of this intuitive God-given ability and feeling for design is the Gothic cathedral—a skeleton-stone construction with supports reduced to the last degree and probably destined to remain man's greatest structural accomplishment in stone, for the age of stone masonry has passed. No stress analysis or testing of materials dictated this remarkable structural triumph.

As we have previously indicated, the marriage of modern science to the ancient practical art of engineering construction was not accomplished without some complaints from those who saw what they thought to be good reasons why the two should not be joined together. On the engineering side, we have an amusing skit by a pioneer American humorist, the engineer George H. Derby, who wrote under the name of John Phoenix. His "Report on the Location of the San Francisco-Mission Dolores Railroad" describes the wonderful scientific equipment and the amusing adventures of the many "ologists" who were included in this remarkable party for the location of a line between two points well within the present city limits. Phoenix wrote in the early fifties, when this controversy was just beginning, but it is interesting to note that, 20 years later, John C. Trautwine excluded from his famous engineers' "pocket-book" the work of Rankine, Moseley and Weisbach, as he considered their writings to afford "little more than striking instances of how completely the most simple facts may be buried out of sight under heaps of mathematical rubbish."

That this effort "to reduce engineering to a science" met with similar antagonism from the representatives of science is indicated by the statement of H. A. Rowland, said to have been "America's leading physicist of half a century ago":

> It is not an uncommon thing, especially in American newspapers, to have the *applications* of science confounded with pure science; and some obscure American who steals the ideas of some great mind of the past, and enriches himself by the application of the same to domestic uses, is often lauded above the originator of the idea, who might have worked out hundreds of such applications, had his mind possessed the necessary element of vulgarity.

Nevertheless, the reduction of engineering to a science proceeded, and one of its immediate results was the recognition that much of the technic of engineering design rested on a basic knowledge of mathematics, physics and other natural sciences, and could thus be taught more effectively through the formal processes of the classroom than through the older method of apprenticeship. Our modern engineering schools were born of this movement and, as if to clinch the argument, were very generally called scientific schools. Before 1850 there were but two such schools in the United States. By 1870 there were 70. Our engineering colleges have continued to lead in this scientific movement of which they were born.

Yet the young scientific graduate had a difficult row to hoe during the middle years of the last century. He lacked experience in construction and, without such experience, was ill-prepared to reconcile his exact knowledge with the requirements of economic production. He was apt to forget that design is not an end in itself but simply a step to intelligent construction. Our engineering colleges can teach fundamentals, but they cannot replace the experience of apprenticeship which is still essential in the education of the engineer. The modern functional organization of engineering offices does make it possible for a young engineering graduate to make his skill immediately useful, but we must not persuade ourselves, for this reason, that our colleges can give a boy a complete engineering education. This viewpoint will lead only to narrow technical specialization, training not education, and our colleges will become still further divorced from the practical problems of production and application, and a restricted, sterile outlook will inevitably result.

In the writer's opinion, we are suffering today from this trend toward narrow scientific and technical specialization not only because it has too often led us to ignore the necessities and values of a general education for the professional man—lawyer, doctor or engineer—but also because it has built up water-tight compartments

within science and engineering which retard the full employment in all branches of the new methods and technics developed in other branches. Technological change is moving on apace and its continued movement demands a more complete utilization, a wider application, of available technics. This movement is now going forward in science and will undoubtedly increase in importance in engineering.

The final factor which limits engineering progress is economic and social demand. Great engineering works, structures or plants, are not built unless economic wants or social needs make their financing possible. Furthermore, as the late William Barclay Parsons remarked: "It is not the technical excellence of a design which alone determines its merit, but primarily its adaptability to the economic and social needs of the time."

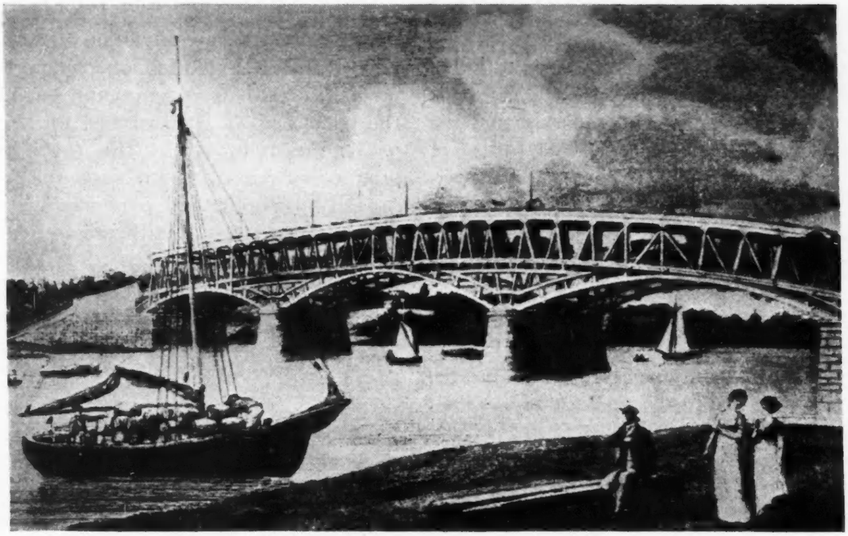
The extent to which economic considerations determine not only whether an engineering work is or is not undertaken, but also its form and details of design, is a revelation to many laymen. The great railroad engineer, Wellington, defined an engineer as a man who could do that well for one dollar which any bungler could do with two, after a fashion. While the engineer endeavors to use the materials and control the forces of Nature for the use and convenience of man, he must work under the limitations of economic law. Necessarily, therefore, engineering progress is conditioned not by the potentialities of current technical knowledge but by economic conditions and demands which determine use.

The fundamental advantage of science in structural design, for example, is in the saving of materials thereby effected. Science has also, of course, made bigger structures safe ventures rather than impossible gambles, but economy of materials affects all designs, big or small. In our earlier days, common constructional materials—timber and stone—were plentiful and relatively cheap. Science had, therefore, little to offer in practical design. Such pioneer works as Whipple's stress analysis applied to bridges of 1851 were stillborn and found their way into practice but slowly. With the advent of more costly materials—iron and steel—and of more involved forms—trusses, braced arches and cantilevers—this situation changed. The rate of flow of science into technology was accelerated. The over-all control of economic factors still remained, however, and it is this economic-technical inter-relationship that is, I believe, the crux of the situation in which we find ourselves today.

At least one modern activity has continued to grow by leaps and bounds all through the depression of the last ten years. In 1928 some $75,000,000 was spent on industrial research. By 1938 this figure had reached $180,000,000 and, in 1941, it was estimated that over $300,000,000 was spent in industrial and institutional research. We have been and now are—for the war has further accelerated research, much of which will have peacetime values—accumulating a tremendous technological backlog, some of which has been currently translated into practice but much of which is awaiting the signal to go—an opportunity for application. Those most competent to express an opinion believe that, when the war is over, we will have, at long last, a real demand for consumers' goods and a real opportunity for progress.

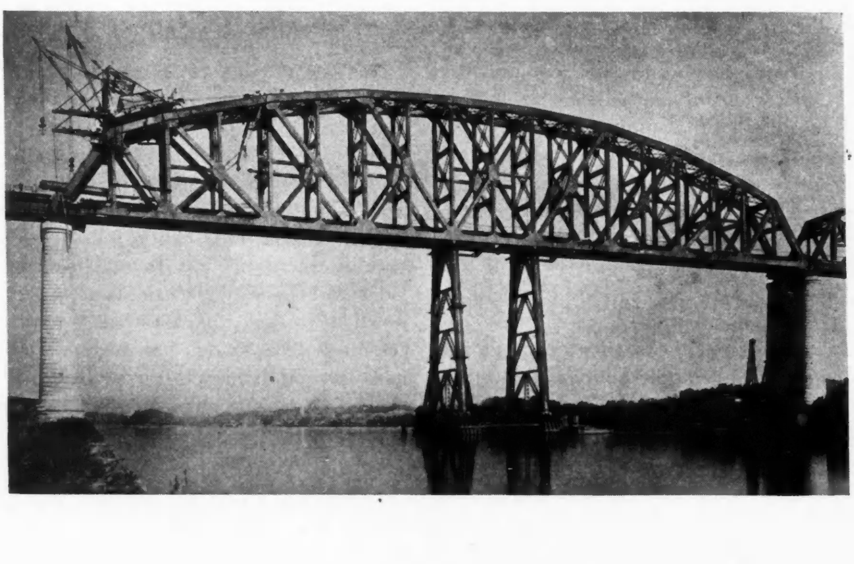
The extravagant boom of the twenties and the discouraging depression of the last decade have, however, demonstrated beyond all doubt that earlier economic controls will not insure the equitable distribution of the proceeds of technological change to all the people. These advances can give to business an increased return on invested capital, to labor higher wages, and to the public a higher standard of living, by increasing the purchasing power of the dollar. But the avarice of capital or of labor may nullify the possibilities of progress by grabbing all the margin and leaving nothing, or less than nothing, for the public. Of what avail are goods which are priced so high that the public cannot buy, or the two dollars labor now has that will purchase no more than the one the wage earner had in former years? Furthermore, social security—health, old age and unemployment insurance—now demands a share in the proceeds of our economic life.

The function of government in the postwar world must be that of impartial dispenser of justice—the balance wheel of our economic order. But business, industry and labor must shoulder the main problems which remain to be solved, and establish the main essential controls which must be set up, if this postwar revival is to be



Above, the "permanent" bridge over the Schuylkill at Philadelphia, built by "the ingenious" Timothy Palmer, 1804–06. A main span of 195 ft. While used for relatively light loads it was a *tour de force* in the design of timber framework.

Below, the great 600-ft single truss span of the Castleton Bridge over the Hudson on the New York Central Lines, 1924. Using steel and planned for heavy modern train loads this work was made possible only by a scientific and thoroughly rationalized process of stress analysis and design. Figure shows work almost complete with two temporary supports still in position.



more than a flash in the pan, if technological change, scientific and engineering progress, are to be translated into higher standards of living for all the people. The only alternative is some form of national socialism, bureaucracy and the chaos of political opportunism. The future of science and engineering will thus depend, primarily, on the kind of world we live in after the war. Too many of us have lost confidence and see little hope of continued progress. Yet the matériel for a great peacetime advance is available. If we can avoid factionalism and cooperate in planning to use science and engineering for the benefit of all our citizens, there is open to us a new era in which "the integration of the practical capacity to do with the intellectual capacity to understand" will raise western civilization to new levels of faith and accomplishment.

A Course in Applied Spectroscopy

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WHILE spectroscopy as a classroom subject was once rarely heard of outside of physics, it has in recent years come to occupy an important place among the subjects taught by many other departments. Its chief function in these other branches of knowledge is that of analyzing substances for small amounts of certain metals or trace elements. The growth of this type of analysis and the demand for training in this field has shown a marked increase in the last few years. Part of this is due to the discovery that minute amounts of certain metals play an important part in plant and animal behavior. Still another factor has been industry's increased interest in new scientific methods.

These measurements of minute amounts or of trace elements are more easily made with the spectroscope than with any other instrument, and industry has discovered the spectroscopic method to have the advantages of speed and convenience as well. Today industry is in dire need of spectroscopic apparatus and men trained in the field.

In many universities the burden of preparing technicians for spectroscopic analysis falls upon the department of physics. While most departments have in the past taught a course in spectroscopy, it has been of the type dealing directly with atomic and molecular structure and not one of the applied type. These two types are quite different in both their purpose and subject matter, and in planning a course in applied spectroscopy this difference cannot be ignored. We have recently reorganized our course in applied spectroscopy, and this article is based on our experience and the departmental discussions which were associated with the reorganization. We feel that while many of the problems encountered were peculiar to our own department, some are general enough to be of value to others.

PROBLEMS OF ORGANIZATION

It became evident during the planning of our applied course that it should have for its objectives some of those found in engineering courses, namely, the teaching of certain testing methods and the training of students in the operation of apparatus that had been designed for certain specific tasks. This called for some sacrifice in the allotment of time to mathematical derivations and theoretical discussions, a sacrifice that, needless to say, was reluctantly made. No concessions were made, however, with regard to basic principles, since it was generally believed that a few basic principles are worth a large number of detailed applications. This is not always appreciated by the student, especially in the laboratory where he expects to duplicate the

popularized feats of the industrial testing laboratories. It was found that an effective way to keep the laboratory an experimental one and to prevent it from deteriorating into an exercise in throwing levers in a little-understood machine was to use apparatus with a minimum of accessories. Needless to say, this had the added advantage of economy. The omission of rigid benches and lens systems in front of the spectrographs added flexibility as well as instructional value to the equipment. One unfortunate result of this policy of letting the student adjust the optical equipment was to increase the likelihood of errors in his results. At the finish of many experiments the student found himself wanting to repeat the experiment with some minor change in optical alinement or slit width but was discouraged from doing so because of the lack of time.

Another puzzling question in laboratory organization is that of the choice of apparatus. With industry's increased demands, laboratory apparatus has appeared upon the market at such a rapid rate as to make it almost impossible to obtain even a small fraction of that available. While we did not feel obligated to acquaint our students with all the latest tools, we did wish, after having taught the basic principles, to let them manipulate as much modern equipment as possible. An attempt was therefore made to acquire a large variety of instrument types, sacrificing quality if necessary.

Because applied spectroscopy is taught to students majoring in other fields, there is always the problem of picking the subject matter that will prove most satisfactory for the class as a whole. The subject material which we have found to be most useful to the student and which still meets the restrictions of our limited equipment is outlined in the next section. At the present time spectrographic analyses of alloys are being emphasized because of the industrial demand for men trained in this field.

NATURE OF THE COURSE

In our course the class meets for two one-hour lectures and one three-hour laboratory each week. The course is of intermediate grade and contains juniors, seniors and some students working for advanced degrees. Many of the students are prospective chemists or chemical engineers. We also have a number of high school teachers taking the course as part of their graduate work. Because of the large number of students from other departments, the lectures are conducted so as to review as much elementary physics as possible. The subject matter is well suited for this treatment and permits the teacher not only to offer the specialized material of the course but also to give a review of elementary physics that is sorely needed by students who take only an occasional course in our department.

Because applied spectroscopy covers such a variety of subjects, it stands to reason that no one textbook would ever be found to be satisfactory by all instructors. At present there are few books in the field designed as textbooks, but on the other hand there are a number of good reference works. These books are described briefly in the final section.

Exercises or problems are given wherever possible. Altogether there are 35 problems, none of which requires calculus. This number is regarded as far too small and is being gradually increased.

There follows a brief outline of the lecture material as given in our course. Typewritten notes based on this outline are loaned to the students and are used in place of a regular text.

Introduction: Refraction and interference method of spectra formation; historical growth of the subject; advantages as a method of chemical analysis.

Spectrum lines: Angstrom and Rowland maps; international scale; energy level diagrams; multiplet nature of lines; natural line width; Doppler width; line reversal; splitting of lines in magnetic and electric fields.

Line classification: Hartley's, de Gramant's, Ryde and Jenkins', and Lundegårdh's tables of persistent lines; Russell's ultimate, penultimate and antepenultimate classification; lines in principal, sharp and diffuse series; tables of line wave-lengths.

Prism spectrograph: Angle of minimum deviation; theoretical resolving power and dispersion of prism; purity of a prism spectrograph; light gathering power; loss of light within spectrograph; multiple prism mounting; Littrow mounting; Cornu prism; Wadsworth mounting; Amici prism; constant deviation prisms.

Grating spectrograph: Theoretical resolving power of grating; dispersion; Lyman and Rowland ghosts; intensity distribution within orders; transmission, reflection and concave gratings; Rowland, Paschen and Eagle mountings; grating manufacture.

Extra-spectrographic optical systems: Intensity dependence upon distance to source with and without lens; spherical and cylindrical lenses; double lens system with parallel light; position of rotating sectors.

Arcs: Positive-crater carbon arc; standard iron arc; negative electrode carbon arc; high potential alternating-current arcs; interrupted arcs; temperature distribution in carbon arc; potential distribution in carbon arc; low-pressure arcs.

Sparks: Condensed spark with induction; frequency relationship in condensed spark; power in condensed spark discharge; condensed spark regulated with synchronized auxiliary spark; uncondensed spark; Tesla coil spark.

Flames: Bunsen flame and its temperature; acetylene flame with aspirated liquid; Saha's theory of thermal ionization.

Other discharge methods: Under-liquid arcs and sparks; electrodeless discharge; exploding wires.

Photography: Composition of photographic plate; method of image formation; the H and D curve; effect of developing time on contrast constant; plate speed at spectroscopic level; common reducing agents, accelerators, preservatives and restrainers in developers; effect of temperature on development; common plate types and their special uses.

Densitometry: Definition of optical density; methods of light reduction including sectors, variable apertures, wire screens, optical wedge and crossed Nicols; Hartman comparator; basic principles of microdensitometer; photronic cell with sensitive meter; photoelectric cells with amplifier and portable meter; recording densitometers.

Quantitative methods: Steps in determining absence of certain elements; coincidence lines; length of line method; time of consumption method; homologous line pair method; working curves with and without internal reference line; step sector; logarithmic sector; formulas for calculating concentration from density measurements on two standards with internal reference; smallest amounts detectable by different methods; variation of line intensity with physical structure and chemical composition of medium.

Treatment of samples: Digestion of organic samples; acid solution treatment of powders; carbon pastils; use of buffers; sealing carbon electrodes; purifying carbon electrodes; concentration of liquids by electrolysis and evaporation; introducing liquid into discharge by spraying, capillary action and immersion.

Absorption spectroscopy: Lambert's and Beer's laws; extinction, extinction coefficient and molecular extinction coefficient; appropriate light sources, solvents and cells; dependence of optical density in photographing absorption spectra on cell length or concentration; concentration measurements using standard solution exposed for various times; divided-beam method with sector; notched echelon cell method; empirical formula for band positions of certain liquid bands; similarity among band patterns and their relationship to chemical structure; measurement of international units of vitamin A by absorption spectroscopy.

Infra-red spectroscopy: Range of near and far infra-red; transmission limits of various substances; blackbody radiation; Stefan's and Wien's laws; infra-red light sources and detectors; prism spectrographs; grating spectrographs; pure rotation and rotation-vibration bands of HCl vapor; prominent bands in liquid hydrocarbons and water; prominent bands in the solid carbonate minerals; emission spectra in explosions.

CONTENTS OF LABORATORY INSTRUCTION

The experiments adopted for this course were chosen so as to introduce the student to as many different spectroscopic methods as possible, and at the same time to give him laboratory work that was really experimental and not just demonstrations. The 20 experiments listed below fall into six groups: (1) visual spectroscopes, (2) spectrographs, (3) quantitative and qualitative analysis with emission spectra, (4) quantitative and qualitative analysis with absorption spectra, (5) qualitative analysis in the near infra-red and (6) analysis of line and band spectra. In these experiments the students familiarize themselves with a Cornu prism spectrograph, Littrow and Wadsworth mountings, a direct-vision spectroscope, a Rowland mounting for the grating, a direct-current arc, a condensed spark, a high potential alternating-current arc, discharge tubes, lens systems, photographic developing apparatus and a densitometer.

Our developing equipment includes the chemicals, museum jars for developing the film or plates, and the usual washing tanks. For contrast work we use Eastman Process plates with D-11 developer, Eastman Spectrum Analysis No. 1 plates with D-19 developer and Eastman Spectrum Analysis No. 1 on 35-mm film with D-19 developer. For low contrast or fast work we use Eastman 50 plates with DK 50 developer and Super-XX Panchromatic 35-mm film with DK 20 developer.

The 20 experiments require more time than is available in a three-hour, one-semester laboratory, so that only part of these are performed by any one student. The choice depends on his interest and background. Those who are preparing to teach or who are already teaching in secondary schools are the only ones to whom the second and third experiments are assigned. Those who have had a course in optics or physical chemistry omit the first experiment.

1. *Dispersion curve for spectrometer and location of absorption bands.* Obtain a curve of wave-length *versus* angle

setting using mercury, neon and sodium lines; estimate the instrument's purity in the yellow portion of the spectrum, and measure the wave-lengths of absorption bands in chlorophyl and haemalized blood. *Equipment:* student spectrometer with deflecting prism at slit, mercury and sodium arcs, neon bulb, tungsten-filament lamps, solutions of haemalized blood and chlorophyl.

2. *Direct-vision spectroscope and identification of Fraunhofer lines and gases.* Focus and adjust a direct-vision hand spectroscope; determine certain gases in Plücher tubes by their lines; identify and measure several Fraunhofer lines as well as the Swan bands in a bunsen flame. *Equipment:* direct-vision spectroscope, several Plücher tubes, induction coil, colored charts of spectra, bunsen flame.

3. *Doppler effect and stellar spectra.* Project a photograph of the spectrum of a spectroscopic binary such as Mizar onto a screen; measure the maximum shift in wave-length; calculate the star's line-of-sight velocity; from photographed spectra of stars τ Sco and 10 Lac determine their classification using other photographs of star classes for comparison. *Equipment:* spectrum of a spectroscopic binary,[1] projection lantern, photographs of certain star spectra.[2]

4. *Foci and linear dispersion of a Rowland grating.* Locate the position of the primary focus by adjustment of the vertical slit; locate the secondary focus by moving a horizontal slit along the optic axis; photograph the mercury, neon and sodium spectra; measure the position of a number of known lines; establish the linear dispersion in angstroms per millimeter. *Equipment:* grating spectrograph with Rowland mounting, sodium, mercury and neon arcs, horizontal slit about 1 mm wide, ground-glass screen fitted into the camera holder of the spectrograph.

5. *Extra-spectrographic lens and slit mountings.* Measure the intensity of light entering a model of a spectrograph as both a rectangular-shaped light source and a point source are moved up to the slit; measure it when a converging lens is placed in various positions between a rectangular light source and the slit; repeat this when both the focused light source and lens are moved; measure the intensity of light transmitted by the slit with a spherical and then a cylindrical lens; observe the mounting of a lens in front of the slit that is to focus the light source on a horizontal slit located just in front of the spectrograph's objective lens; observe the mounting of two lenses such that the lens closest to the source is focused on the slit and such that the source is focused on a horizontal slit in front of the lens closest to the spectrograph. *Equipment:* optical bench with vertical slit and lens to serve as model of spectrograph's optical system, photronic cell mounted behind this lens, galvanometer, cylindrical lens, several double convex lenses, 6-v ribbon filament lamp, horizontal slit of adjustable width.

6. *Calibration of linear scale for a small Littrow spectrograph.* Observe the principal parts of the Littrow mounting spectrograph; photograph the mercury arc spectrum; measure the positions of all strong lines either on the metric scale or by means of a traveling microscope; plot a graph of wave-length *versus* scale reading; determine the linear dispersion in angstroms per millimeter at different positions on the spectrogram. *Equipment:* small Littrow spectrograph, mercury arc, viewing box, photographic developing equipment, tables of lines, traveling microscope.

7. *Identification of unknown metal salt using carbon arc.* Photograph a direct-current carbon arc having an unknown metal salt sample placed within a hole in the positive electrode; locate on the spectrogram the reversed lines and pole lines; measure the line positions and wave-lengths of all strong lines; even though the dispersion is so poor as to prevent the elimination of coincident lines, identify the principal metal in the sample. *Equipment:* small Littrow spectrograph, medium grade of pure carbon rod, 110-v d.c. arc with 10 ohms resistance, developing equipment.

8. *Identification of persistent lines in a condensed spark spectrum.* Observe the principal adjustments to be made on a medium-size quartz spectrograph; photograph condensed spark spectra, using copper or aluminum rods and employing self-induction for one spectrum and none for the next; identify the persistent lines with the aid of the better-known persistent-line classifications; obtain correction data for the photographed scale; determine the linear dispersion at various portions of the spectrum. *Equipment:* medium-size quartz prism spectrograph, condensed spark in which it is possible to short circuit the inductance, metal rods for electrodes, developing equipment, tables of persistent lines.

9. *Photographic plate constants and density measurements.* Photograph the spectrum of a tungsten-filament lamp for different time intervals using first an Eastman Process plate and then an Eastman 50 plate; measure the optical density at a chosen wave-length with a recording densitometer; plot the optical density as a function of the logarithm of the exposure time; determine the relative speed and contrast of these two plates. *Equipment:* medium-size quartz spectrograph, tungsten-filament lamp, microdensitometer, developing equipment.

10. *Qualitative analysis of soil for 24 elements using master spectrogram for reference.* Photograph the arc spectrum of a soil sample; project the spectrogram next to the laboratory master spectrogram and determine the presence or absence of 24 specified elements; examine the possibility of coincidence for one element using only wave-length tables and the spectrogram; locate the positions of coincident-free sensitive lines for two elements not on the master spectrogram. *Equipment:* grating spectrograph, 110-v d.c. arc, master spectrogram on cards with iron lines and suitable sensitive lines indicated, projector for 35-mm film, sets of wave-length tables, developing equipment.

11. *Construction of working curves for cadmium in tin.* Make spark spectrograms of nine pairs of tin rods containing cadmium varying in concentration from 1 to 9 percent; measure the density of a chosen cadmium line, a tin line and a region containing bands; plot the density of the cadmium as a function of the logarithm of the concentration for working curve I; plot the difference in the density of the cadmium line and that of the tin line *versus*

[1] Lantern slides from the Yerkes Observatory (Univ. of Chicago Press).

[2] W. W. Morgan, P. C. Keenan and E. Kellman, *An atlas of stellar spectra* (Univ. of Chicago Press, 1943).

the logarithm of the concentration for working curve *II*; and plot the density of the cadmium line minus that of the bands *versus* the logarithm of the concentration for working curve *III*. *Equipment:* medium-size quartz prism spectrograph, recording densitometer, nine pairs of tin rods with cadmium varying in concentration from 1 to 9 percent, condensed spark, developing equipment.

12. *Quantitative measurement by two standard methods and working curves method.* Obtain spark spectrograms of electrodes possessing 1 percent cadmium in tin, 9 percent cadmium in tin, and an unknown percentage of cadmium in tin; measure the densities of certain cadmium and tin lines as well as those of the bands; measure the unknown cadmium concentration using the working curves of experiment 11; measure this concentration using the two standards and using both the tin line and the bands as internal standards, or reference lines. *Equipment:* medium-size quartz spectrograph, condensed spark, electrodes, densitometer, developing equipment.

13. *Quantitative measurement using optical wedge or rotating logarithmic sector.* Photograph the spark of 1-percent, unknown percentage, and 9-percent cadmium-in-tin electrodes after the light has passed through either an optical wedge or a logarithmic sector; project and measure the lengths of a cadmium line and a tin line; calculate the concentration of the unknown from these measurements without using the tin line as an internal standard and then with it. *Equipment:* medium-size quartz spectrograph, condensed spark, electrodes, optical wedge or rotating logarithmic sector, projection lantern, developing equipment.

14. *Quantitative measurement using the homologous line pair method.* Obtain spectrograms of tin electrodes containing 10, 2, 0.2, 0.1, and 0.05 percent of cadmium in tin; measure the concentration of these samples using a laboratory table of homologous line pairs. *Equipment:* medium-size quartz spectrograph, electrodes, condensed spark, projection lantern, developing equipment.

15. *Wave-length measurement of absorption limits and bands.* Obtain spectra of a continuous source after it has passed through such materials as window glass, Plexiglass, sun goggles, quartz, Corex A glass, a 1-mm cell of CS_2 and a cell containing toluene vapor; tabulate the band widths and positions as well as the transmission limits. *Equipment:* hydrogen discharge tube, medium-size quartz spectrograph, assortment of aforementioned transmitting materials, viewing box, developing equipment.

16. *Measurement of extinction coefficients and location of benzene bands.* Obtain spectra of a continuous light source after it has passed through increasing thicknesses of a solution of benzene in alcohol; measure the frequency of the band centers, plot them against arbitrarily chosen numbers for the band, and determine the fundamental frequency as well as the order of the harmonics; measure on each spectrogram the optical density at a given wave-length, and from a graph of the optical density *versus* the length of the absorbing path obtain the product of the extinction coefficient for the solution and the gamma of the plate. *Equipment:* hydrogen discharge tube, medium-size quartz spectrograph, absorption cell with adjustable length up to 1 cm, solution of 1 part of benzene in 1000 parts of ethyl alcohol, recording densitometer, developing equipment.

17. *Concentration measurements and match points in absorption spectra.* Photograph alternately eight spectra of a continuous source through a solution of benzene in alcohol and eight spectra through the alcohol alone, the latter being taken for different times; mark the finished film at matched points; determine the concentration of the benzene using tables of molecular extinction coefficients. *Equipment:* hydrogen discharge tube, medium-size quartz spectrograph, 8-mm quartz absorption cell, ethyl alcohol, solution of 1 : 1000 benzene in ethyl alcohol, viewing box, developing equipment.

18. *Analysis of the atomic spectrum of sodium.* Photograph the spectrum of sodium using a direct-current arc; measure the wave-lengths of five lines in the principal series, three in the sharp and three in the diffuse; convert these values to wave numbers and with the wave numbers of both the series limits and the first lines in the diffuse and sharp series furnished, determine the energy states for sodium in wave numbers; construct a Grotrian diagram. *Equipment:* 110-v d.c. carbon arc containing a sodium salt, medium-size quartz spectrograph, viewing box, developing equipment.

19. *Electronic bands of* NO *and* N_2. Photograph the spectrum of a nitrogen discharge using a Plücher tube; photograph the spectrum of the high-potential alternating-current arc between carbon electrodes in air; measure the nitrogen band-heads between 5750 and 6200A as well as the air band-heads between 2380 and 4600A; identify the N_2 bands by referring to Jevons,[3] pages 78 and 82; construct appropriate energy level diagrams for this vibrational sequence as well as for the electronic levels; using Pearse and Gaydon's tables of band spectra,[4] identify the air bands in the ultraviolet region. *Equipment:* Plücher tube filled with nitrogen, induction coil, 10,000-v transformer rated at 5 kw to be used to excite a.c. arc, grating spectrograph, viewing box, developing equipment.

20. *Infra-red spectrometer and absorption.* Measure the emission of a Nernst glower in the wave-length range from 1 to 12 microns; calculate the temperature of the glower from the wave-length of maximum emission; measure the percentage of infra-red radiation transmitted by a photographer's black-red filter, by window glass and by Plexiglass. *Equipment:* Nernst glower, infra-red spectrograph with rocksalt prism having a Wadsworth mounting and a range up to 12 microns, thermopile with galvanometer and scale.

BOOKS ON APPLIED SPECTROSCOPY

Listed here are a few books that we have found almost indispensable for our course. This very incomplete list does not include the usual text-

[3] W. Jevons, *Band spectra of diatomic molecules* (Physical Soc., London, 1932).

[4] W. B. Pearse and A. G. Gaydon, *Identification of molecular spectra* (Wiley, 1942).

books on optics and the infra-red which we also employ. A complete bibliography can be found in Brode's book, page 316.

Wallace R. Brode, *Chemical spectroscopy* (Wiley, 1939). This is the only book in English primarily designed as a textbook in applied spectroscopy. It covers emission, absorption, infra-red and Raman spectra. A large portion of the book is devoted to absorption spectroscopy and its relationship to molecular structure. Detailed instructions for 12 experiments are given, and the book can be used as a combination laboratory manual and classroom text. About one-fifth of the material is devoted to instructions on laboratory experiments, another one-fifth to spectrum charts and tables, and the remainder to lecture material.

Wolfgang Seith and K. Ruthardt, *Chemische Spektralanalyse* (Springer, Berlin, 1938). In German. This book is written as a laboratory manual and covers the important features of the field very well. Twenty-two different experiments are discussed. While there are no experiments on the infra-red and only one that deals with absorption spectroscopy, those on emission are very complete.

Donald Murgatroyd Smith, *Metallurgical analysis by the spectrograph* (British Non-Ferrous Metals Research Association, London, 1933). A short book with detailed instructions for analyzing metal alloys. Besides covering the methods in general, it also includes a detailed account of the assaying of zinc, tin, lead and copper.

Walter Gerlach and Eugen Schweiter, *Die Chemische Emissions—Spektralanalyse* (Leopold Voss, Leipzig, 1930). In German. This comprehensive work is replete with a large variety of testing methods, clear photographs of apparatus and illustrative examples. A large section is devoted to spectroscopy in medicine and mineralogy. A table of persistent and coincident lines is included. About one-third of the book has been translated under the title, *Foundations and methods of chemical analysis by the emission spectrum* (Adam Hilger, London, 1937).

Harold Warris Thompson, *A course in chemical spectroscopy* (Oxford Univ. Press, 1938). Just enough about methods and apparatus is given in this book to help one in performing certain experiments on line and band spectra. The book is built around eight experiments, some of which are the rotational structure of a band in molecular spectrum, predissociation spectra, and the plotting of potential energy curves.

Henrik Lundegårdh, *Die Quantitative Specktralanalyse der Elemente* (Gustav Fischer, Jena, 1934), Vols. I and II. In German. The formation of spectra by using flames is treated with great elaboration in these volumes, which serve as the best references for this type of spectrographic analysis. There are also examples worked out for a large number of spectroscopic analyses, the data being given in a very complete form. One of the volumes contains a fine set of photographs showing the spark spectra of certain metals in solution as their concentration is diminished. There are also fine reproductions of flame spectra.

E. C. C. Baly, *Spectroscopy* (Longmans, Green, London, 1927), Vol. I. This volume consists of 298 pages of useful information on all phases of spectroscopy. Much space is devoted to the mathematical theory of spectrographic equipment and it is a very useful book for information on the optics of spectrographs. It is the closest thing available to an encyclopedia on spectroscopy in English.

G. R. Harrison, *Wavelength tables of 100,000 spectrum lines* (Wiley, 1939).

H. Kayser and R. Ritschl, *Tabelle der Hauptlinien der Linienspektra Alle Elemente* (Julius Springer, Berlin, 1939).

D. M. Smith, *Visual lines for spectrum analyses* (Adam Hilger, London, 1928).

I wish that old Copernicus could see
How, through his truth, that once dispelled a dream. . . .
And seemed to dwarf mankind, the spirit of man
Laid hold on law, that Jacob's ladder of light.
. . . The records grow
Unceasingly, and each new grain of truth
Is packed, like radium, with whole worlds of light.

—Alfred Noyes

A New Boyle's Law Apparatus

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Purdue University, Lafayette, Indiana

THERE are many forms of apparatus suitable for the verification of Boyle's law in the student laboratory. Most of these involve the reading of pairs of values of pressure and volume of the gas, from which the constancy of the product may be seen. Other forms, less familiar in American laboratories, are of the semi-automatic type; that is, they yield directly a graph of v versus p, permitting a verification of Boyle's law by recognition of the resulting rectangular hyperbola. Such devices are described in the literature;[1] they have the disadvantages of being complicated in construction and of requiring large quantities of mercury. Moreover, the hyperbola is a curve whose exactness of form is difficult to check geometrically.

The present device is based on the idea, originally due to Melde, of the "capillary barometer." In his method[2] a capillary tube of medium bore, sealed at one end, contains a volume of air confined in the closed end of the tube by means of a thread of mercury. The tube may be held at various angles of inclination, the volume of the air and the projection of the mercury thread on the vertical direction being measured in each case. Multiplication of each volume reading by the algebraic sum of the corresponding vertical projection of the mercury thread and the barometric height yields a series of sensibly constant values. The difficulty with this procedure is that the measurement of vertical heights "in mid-air" or the measurement of angles is not accurate. In addition, the tube is likely to receive excessive handling, introducing errors because of the resultant change in temperature.

In order to overcome these difficulties and to provide direct, graphical verification, the present apparatus employs such a tube as the foregoing, permanently mounted on an axle so that it can rotate in a vertical plane. This is shown schematically in Fig. 1. The experimental procedure consists in fixing the tube at various angles θ to the vertical and marking in each instance the position of the outer end A of the air space on a piece of paper mounted on a board behind the tube.

Let k be the length of the mercury thread, and let r be the length of the air space—that is, the volume of the air per unit cross section of the tube. Let the barometric height, expressed in the same units as k and r, be denoted by B. Then, if Boyle's law is valid, we must have

$$r(k\cos\theta+B)=\text{const.} \qquad (1)$$

This is the polar equation of an ellipse with one focus at the origin and the nearest vertex on the initial line. Hence, if all the points obtained by the foregoing procedure are found to lie on such an ellipse, this constitutes a verification of Boyle's law. The paper may be removed and the ellipse drawn by the familiar method using a thread looped around two pins inserted at the

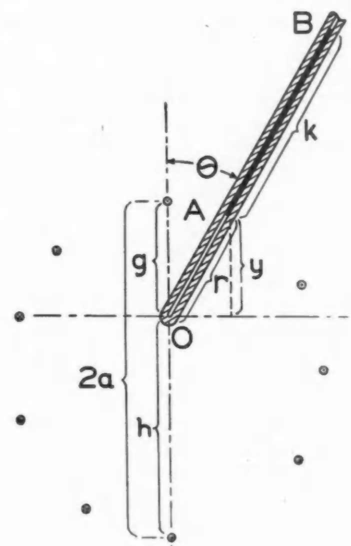

Fig. 1. Schematic diagram of the device.

[1] See, for example, Rosenberg, *Experimentierbuch* (Hölder, Vienna, 1913), vol. 2, pp. 88–89.
[2] Melde, Wied. Ann. **32**, 659 (1887).

foci (Fig. 2.). The points will be found to lie on or very close to this curve.

One way of gaging the accuracy of the method is to use it to calculate the atmospheric pressure,

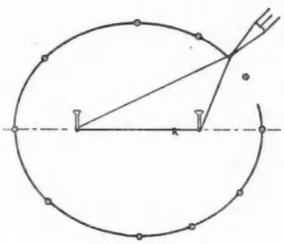

FIG. 2. Construction of the ellipse.

comparing the value thus obtained with the direct reading of a barometer. The following procedure may be used. For the vertically upward and vertically downward positions of the tube (Fig. 1) it must be true that

$$g(B+k)=h(B-k), \tag{2}$$

from which

$$B=\frac{h+g}{h-g}k. \tag{3}$$

The accuracy is somewhat increased if, in place of using g as one of the distances actually measured on the graph, the longer segment $2a$ is used. Then, since $g=2a-h$, Eq. (3) becomes

$$B=\frac{a}{h-a}k. \tag{4}$$

The fraction $(h-a)/a$ is readily seen to be equal to the eccentricity of the ellipse. Comparison of the value of B calculated from Eq. (4) with the barometer reading reveals an error that is usually less than 1 percent.

Some teachers may not wish to use a method that employs properties of the ellipse, and may prefer to have the result in the usual form of a set of constant values of the product pv. Such products may, of course, be obtained readily from the data already taken. It is only necessary to draw radial lines from O to the experimentally obtained points (Fig. 1) and then, for any such line, to measure r and y. Substitution of y/r for $\cos\theta$ in Eq. (1) gives

$$r\pm(k/B)y=\text{const.}, \tag{5}$$

the positive or negative sign being used according as the radius vector in question is above or below the horizontal line through O. Constancy of this expression is the test for the validity of Boyle's law. Obviously the accuracy obtained by this means of reducing the data will not be as great as that using the ellipse method, since here it is necessary to find by construction the vertical projection of each radius vector, and all distances measured are smaller than those used in the former procedure.

The construction of the apparatus is shown in Fig. 3. The capillary tube T is held in a carrier AM turning on an axle located behind the point

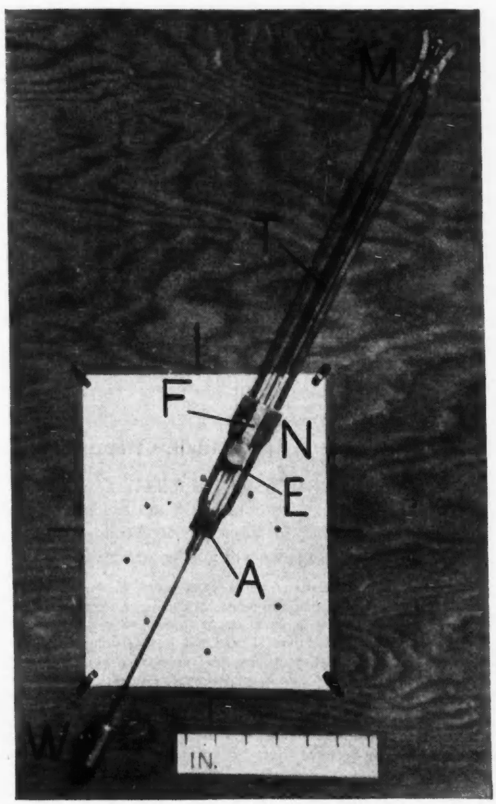

FIG. 3. Design of the apparatus for the student laboratory.

A which marks the sealed end of the tube. The entire assembly turns in a bushing set in the center of a large board mounted on the wall. Spring clips hold in place a sheet of paper which is put in position with the assembly removed. When the latter is replaced, insertion of the axle punches a small hole in the paper, which serves to mark the origin. Vertical and horizontal lines on the board serve to locate the axial directions of the ellipse. *W* is a counterweight. The open end of the tube is bent buttonhook fashion after drawing down the opening to small size so that dust cannot enter readily.

It would be difficult to mark the precise position of the near end of the mercury thread directly, so a special slider *N* is used. This consists essentially of a metal sleeve coaxial with the glass tube, but of larger diameter. The sleeve has a small metal pin fixed at that point of its edge *E* which is nearest the board. To mark the position of the thread, the experimenter lines up the edge of the sleeve with the end of the mercury and then presses down the sleeve against the resistance of the spring *F* which holds it at the other end. Thus the location of the mercury is marked on the paper by means of a small indentation. When a number of such positions have been marked at various angles, the tube assembly is removed, the paper is transferred for convenience to a drawing board and the contruction then proceeds as previously described.

Some of the advantages of the device over the more conventional forms of Boyle's law apparatus may be listed:

(i) It makes use of pressures below as well as above outside atmospheric pressure. In the positions of the tube below the horizontal line, the mercury "hangs" from the contained air.

(ii) It can be shown before a large class by projection. For this purpose, the tube assembly is pivoted in a bushing held in the field of the lantern by means of a slender rod. A water cell is used to prevent heating. The ellipse may be traced on a screen or blackboard. The slider, of course, is not needed in this case.

(iii) Use of the apparatus affords a good opportunity for emphasizing the connection between a physical phenomenon and the geometric interpretation of the law involved.

(iv) The small amount of mercury required is a decided advantage. In the present design, the bore of the capillary is about 1.6 mm and the mercury thread is 30 cm long. Thus the volume of mercury used is but 0.6 ml.

The Early Development of the Bohr Atom

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DURING the first decade of the present century much thought was devoted to theories of atomic structure that would explain the experimental facts which were accumulating at such an amazing rate. These early attempts had succeeded at least partially in explaining some particular result of experimental research.[1] But a really decisive epoch in the history of atomic theory began with the publication of Bohr's series of papers on this subject in 1913. An attempt to explain the absorption of alpha-rays, published early in 1913,[2] may have been instrumental in causing him to attack the monumental task he performed in the following three years. Bohr tried to devise a theory of the structure of the atom that would explain all known experimental facts and predict new discoveries. It is the purpose of this essay to try to show to what extent he succeeded, and to trace the development of his theory through the first three years of its existence.

During this period Bohr published a series of nine papers in the *Philosophical Magazine* and *Nature*, in which various phases of his theory were treated as occasion suggested—the occasion being usually either the necessity of replying to criticism or of adapting the theory to new experimental discoveries. In a tenth paper, written late in 1915, he summarized his ideas and brought them up to date; but before sending the article to the editor of the *Philosophical Magazine* he read two almost simultaneously appearing articles by W. Wilson[3] and A. Sommerfeld[4] that introduced an entirely new viewpoint. Four years later, in 1920, the nine papers mentioned were published in a German translation edited by Hugo Stintzing,[5] and Bohr permitted the inclusion of the tenth paper, which had been withheld from publication.[6]

1. BOHR'S CONCEPTION OF THE RUTHERFORD ATOM MODEL

The striking verification of Rutherford's atomic theory supplied by the experimental evidence of Geiger and Marsden had established Rutherford's model very firmly. Bohr assumed a nucleus of large mass and of dimensions much smaller than the distance between the electrons, which surrounded it in clusters. These clusters were formed by the successive capture by the nucleus of electrons initially nearly at rest, energy being radiated away by each electron during capture. This process would go on until the sum of the negative charges of the captured electrons was numerically equal to the positive charge on the nucleus; the system would then be electrically neutral and would no longer be able to exert sensible forces on electrons at distances from the nucleus great in comparison with the dimensions of the orbits of the captured electrons. "We may regard the formation of helium from the alpha rays as an observed example of a process of this kind, an alpha particle on this view being identical with the nucleus of a helium atom."[7]

Owing to the small dimensions of the nucleus its internal structure would not have an appreciable effect on the configuration of the electrons and hence on the ordinary physical and chemical properties of the atom, which would depend on the total charge and mass of the nucleus. The internal structure would have an influence only on the phenomenon of radioactivity.

[1] For an account of these early attempts, see C. E. Behrens, "Atomic Theory from 1904 to 1913," Am. J. Phys. **11**, 60 (1943).

[2] Bohr, Phil. Mag. **25**, 10 (1913). A summary of the theory proposed by Bohr is presented by Rutherford, Chadwick and Ellis, *Radiations from radioactive substances* (Macmillan, 1930), p. 136.

[3] W. Wilson, Phil. Mag. **29**, 795 (1915).

[4] A. Sommerfeld, Ann. d. Physik **51**, 1 (1916).

[5] Bohr, *Abhandlungen über Atombau* (Vieweg, 1922).

[6] Following is a list of the ten papers: "The binding of electrons by positive nuclei," Phil. Mag. **26**, 1 (1913); "Systems containing only a single nucleus," Phil. Mag. **26**, 476 (1913); "Systems containing several nuclei," Phil. Mag. **26**, 857 (1913); "Hydrogen and helium spectra," Nature **92**, 231 (1913); "Atom models and x-ray spectra," Nature **92**, 553 (1914); "Effect of electric and magnetic fields on spectral lines," Phil. Mag. **27**, 506 (1914); "Hydrogen and helium spectra," Nature **95**, 6 (1915); "Quantum theory of radiation and atomic structure," Phil. Mag. **30**, 394 (1915); "The application of the quantum theory to periodic systems," reference 5, p. 123; "Series spectrum of hydrogen and atomic structure," Phil. Mag. **29**, 332 (1915).

[7] Bohr, Phil. Mag. **26**, 476 (1913).

As to the number of electrons in an atom, Geiger and Marsden from their work on the scattering of alpha-particles assumed that it was one-half of the atomic weight;[8] Barkla[9] had also previously stated that this assumption was confirmed by his research on the scattering of x-rays. In 1913, however, A. van den Broek[10] advanced very plausible reasons for considering that the number of electrons corresponded to the ordinal number of the atom in the periodic table—the *atomic number*. This view was supported by Soddy,[11] through conclusions drawn from work on radioactivity. The nucleus was supposed to be composed of helium nuclei and hydrogen nuclei, with the necessary number of electrons to balance the charge. Bohr used van den Broek's hypothesis. It was assumed that the electrons rotated about the nucleus and were arranged in coaxial rings at equal angular intervals; this, it will be recalled, had been suggested by Nagaoka and Nicholson.[12]

2. BOHR'S BASIC ASSUMPTIONS

The fundamental assumptions made by Bohr, as stated at the conclusion of his third paper, are:

(i) Radiated energy is not emitted or absorbed continuously, as is assumed in ordinary electrodynamics, but only during the transition of systems from one *stationary state* to another.

(ii) The dynamic equilibrium of the systems in the stationary states is determined by the ordinary laws of mechanics, but these laws are not valid for transitions of the systems between the various stationary states.

(iii) The radiation emitted during the transition of a system between two stationary states is homogeneous in frequency, and the relation between this frequency ν and the total radiated energy E is given by $E=h\nu$, where h is the Planck constant.

(iv) For a simple system consisting of an electron revolving about a positive nucleus, the various stationary states are determined by the condition that the ratio of the total energy emitted during the formation of the given configuration to the frequency of rotation is a whole multiple of $h/2$. If the electron orbit is circular, this assumption is equivalent to the statement that the angular momentum of an electron revolving about a nucleus is a whole multiple of $h/2\pi$.

(v) The *permanent state* of every atomic system—that is, the state which results if the emitted energy is a maximum—is determined by the condition that the angular momentum of each electron about the center of its orbit is equal to $h/2\pi$.

In the introduction to his first paper,[13] Bohr states that he is approaching the problem from the viewpoint of Planck's hypothesis, but he extended this hypothesis to suit the conclusions he wished to draw from it. Among the assumptions Planck made, the most revolutionary one was that a vibrating electron does not ordinarily radiate any energy, as one would expect it to, but that when it does so, it radiates a whole quantum, suddenly. Planck assumed that this quantum of energy is determined by the frequency of vibration of the electron, and that this frequency of vibration is determined by the mass of the oscillator and the force applied to it, according to the principles of classical mechanics.

Bohr made a radical, and most important, departure from this assumption. He gave up the idea that the *frequency* is determined by the electron's environment and that the quantum of energy is determined by the frequency, and assumed exactly the reverse. According to Bohr, it is the *quantum of energy* that is determined by the environment—the energy which is liberated when the electron drops from one position in the atom to another. Then the frequency of the resulting radiation is determined by this quantum of energy. In his afore-mentioned assumption (iii), Bohr might more accurately have stated that the relation between the frequency ν and the radiated energy E is given by $\nu=E/h$, instead of $E=h\nu$.

Planck's assumption represented a definite departure from the dynamics of macroscopic bodies, but this assumption of Bohr's is obviously much more divergent.

The way in which Bohr first applied his new assumptions will now be outlined. Consider an atom consisting of a positive nucleus of very small dimensions and charge e' about which a negative electron of charge $-e$ and mass m describes closed orbits. The mass of the electron is negligibly small compared with that of the nucleus, and the electron moves with a speed much smaller than that of light. If it is assumed

[8] Geiger and Marsden, Phil. Mag. **25**, 604 (1913).
[9] Barkla, Phil. Mag. **21**, 648 (1911).
[10] van den Broek, Physik. Zeits. **14**, 32 (1913); Nature **92**, 372 (1913).
[11] Soddy, Nature **92**, 399 (1913).
[12] Behrens, reference 1, secs. **3** and **5**.
[13] Bohr, Phil. Mag. **26**, 1 (1913).

that there is no radiation of energy, the electron will describe elliptical orbits because of the inverse square law. The frequency of revolution f and the length of the major axis $2a$ will depend on the energy E required to remove the electron to an infinite distance from the nucleus. From Newtonian mechanics,

$$f=\frac{\sqrt{2}}{\pi}\frac{E^{\frac{3}{2}}}{ee'\sqrt{m}},\quad 2a=\frac{ee'}{E}. \tag{1}$$

The average kinetic energy of the electron for a complete revolution will be equal to E.

If the system radiates energy because the electron is accelerated, E will continuously increase, and the electron will approach the nucleus, describing smaller orbits with higher frequency, radiating energy in enormous quantities. This phenomenon is not observed in nature.

On the other hand, suppose the electron at the beginning to be at infinity and without appreciable velocity relative to the nucleus. Assume further that after approaching the nucleus, the electron occupies a stationary circular orbit, and that during this binding of the electron by the nucleus radiation is emitted, of a frequency equal to half the frequency of revolution in the stationary state; then apply Planck's hypothesis, by letting

$$E=\tau h\cdot\tfrac{1}{2}f,$$

where τ is an integer. We then get from Eqs. (1),

$$E=\frac{2\pi^2 me^2e'^2}{\tau^2h^2},$$
$$f=\frac{4\pi^2 me^2e'^2}{\tau^3h^3}, \tag{2}$$
$$2a=\frac{\tau^2h^2}{2\pi^2 mee'}.$$

By letting τ assume various integral values, we obtain a sequence of values for E, f and a corresponding to a sequence of configurations of the system. From these considerations, we are led to assume that such configurations will correspond to states of the system in which there is no radiation of energy, states which consequently will be stationary as long as the system is not disturbed from outside. We see that the value of E is largest if τ has its smallest value 1. This case will therefore correspond to the most stable state of the system, that is, to the state resulting from the binding of the electron to the atom in such a way that the largest amount of energy is required to break up the configuration.

As a first check on these primary assumptions, Bohr calculated $2a$, f and E/e, letting $e'=e$, and using the values, $e=4.7\times10^{-10}$ esu, $e/m=5.31\times10^{17}$ esu/gm and $h=6.5\times10^{-27}$ erg sec. He obtained $2a=1.1\times10^{-8}$ cm, $f=6.2\times10^{15}$ sec^{-1} and $E/e=13$ v. These figures are of the same orders of magnitude as the diameters of atoms from kinetic theory, the optical frequencies and the ionization potentials. This was sufficient confirmation for Bohr to proceed to the discussion of dynamic phenomena of the atom on the basis of the afore-mentioned assumptions.

3. EMISSION OF THE LINE SPECTRUM OF HYDROGEN

The system described in Sec. **2** was first tested as a model of the hydrogen atom which would account for the line spectrum of that element. The magnitude of the nuclear charge was assumed to be equal to that of the electronic charge. The energy of this atomic system, when the electron is in the τth orbit, is seen to be given by

$$E_\tau=2\pi^2me^4/\tau^2h^2. \tag{3}$$

If the electron passes from an orbit τ_1 to another orbit τ_2, the transition will result in a difference in energy equal to

$$E_{\tau_2}-E_{\tau_1}=\frac{2\pi^2me^4}{h^2}\left(\frac{1}{\tau_2^2}-\frac{1}{\tau_1^2}\right). \tag{4}$$

This difference in energy, by Planck's hypothesis, results in an emission or absorption of homogeneous radiation of a frequency given by $E_{\tau_2}-E_{\tau_1}=h\nu$, and thus Bohr arrives at his equation for spectral series in atomic hydrogen,

$$\nu=\frac{2\pi^2me^4}{h^3}\left(\frac{1}{\tau_2^2}-\frac{1}{\tau_1^2}\right). \tag{5}$$

Now the Balmer series of the hydrogen line

spectrum is given by the empirically determined expression,

$$\nu_n = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right), \qquad (6)$$

where R is the Rydberg constant, $n_1=2$, and $n_2=3,\ 4,\ 5,\ \cdots$. Hence the constant factor $2\pi^2me^4/h^3$ in Eq. (5) should be equal to the Rydberg constant R as determined from spectroscopic data. Substituting the values for m, e and h accepted at the time, Bohr found this factor to be 3.1×10^{15} sec^{-1}; the experimentally determined value of R was 3.290×10^{15} sec^{-1}. Bohr considered that this agreement between the theoretical and observed values was sufficiently close to serve as a substantiation of his theory, in view of the uncertainty that existed in the determination of the three constants m, e and h in his formula.

Substitution of $\tau_2=2$, $\tau_1=3,\ 4,\ 5\cdots$ in Bohr's formula gives the Balmer series of hydrogen; while $\tau_2=3$, $\tau_1=4,\ 5,\ 6\cdots$ gives the Paschen series, discovered in 1908. Setting τ_2 equal to 1 and τ_1 equal to $2,\ 3,\ 4\cdots$ corresponds to a series of lines in the ultraviolet, and Bohr predicted that these lines would be found. A year later this prediction was verified by Theodore Lyman,[14] who, using a concave grating, discovered a hydrogen series the first line of which corresponded to the wave-length 1216A, the second to the wave-length 1026A.

In these first papers Bohr derived his equation for the series of the hydrogen spectrum in still another way. In the first derivation, as we have seen, he postulated that in the process of capturing an electron the atom emitted homogeneous radiation of a frequency equal to one-half the frequency of revolution of the electron in the final stationary state. Application of Planck's relation $E=\tau h\nu$ to this postulate gives $E=\tau hf/2$. Approaching the problem from a second viewpoint, Bohr made use of the principle that in circular motion under a central force the angular momentum is constant and determines the energy; and he assumed that the angular momentum p of an electron revolving in a circular orbit about a nucleus would be given by $\tau h/2\pi$. These two assumptions, that E is $\tau hf/2$ and that p is $\tau h/2\pi$, were reconciled as follows. The kinetic energy of revolution T is $\frac{1}{2}I(2\pi f)^2$. But p is equal to $2\pi If$ and T is equal to E. Hence $p=T/\pi f=E/\pi f=\tau hf/2\pi f=\tau h/2\pi$.

The system we have just discussed will be in equilibrium, according to the ordinary laws of mechanics, when the electrostatic force of attraction is equal to the centripetal force; that is, when $ee'/a^2=mv^2/a$, where v is the linear velocity of the electron in its orbit. This immediately gives $ee'/2a=\frac{1}{2}mv^2=T$, where T is the kinetic energy of the electron. Bohr assumed that v is small enough so that m does not vary appreciably with v. The potential energy U of the system consisting of a charge $-e$ at a distance a from a charge e' is $-ee'/a$. The total energy E of the system is equal to the sum of the kinetic and the potential energies, or $E=T+U=-ee'/2a$. Hence T is numerically equal to E. If we assume that the angular momentum $ma^2\omega$, where ω is the angular speed, is equal to $\tau h/2\pi$, and use the relation $\frac{1}{2}mv^2=\frac{1}{2}m(\omega a)^2=ee'/2a$, just derived, it follows that

$$a=\frac{\tau^2h^2}{4\pi^2mee'}$$

and

$$E=-ee'/2a=-\frac{2\pi^2me^2e'^2}{\tau^2h^2},$$

which are the expressions previously derived as Eqs. (2). The negative sign in the expression for E indicates that if an electron moves from an orbit τ_1 to another orbit τ_2 closer to the nucleus ($\tau_1>\tau_2$), the total energy of the atom decreases. In this calculation Bohr neglected the magnetic field due to the motion of the electron, since the velocity of the latter is small compared to that of light. The magnetic field at the center of a circle of radius a in which a charge e esu is moving with a velocity v cm/sec is $2\pi ev/ca$ gauss, where c is the velocity of light. The effect of this field on the electron is small compared with e^2/a^2, if $v\ll c$.

As further evidence for the soundness of his hypotheses, Bohr pointed out that with discharge tubes not more than 12 lines of the Balmer series had been observed, whereas in the spectra of some celestial bodies 33 lines of this series had been found, as was to be expected from his theory. With $\tau=12$, the expression for a gives 1.6×10^{-6} cm, which is the mean distance between

[14] Lyman, Nature **93**, 241 (1914).

molecules in a gas at a pressure of 7 mm of mercury; with $\tau=33$, a is 1.2×10^{-5} cm, the mean distance between molecules at about 0.02 mm of mercury. Hence a very low pressure and a large volume of the gas are necessary for the observation of the higher lines of the series.

4. THE SPECTRUM OF HELIUM—THE REDUCED MASS

Using his radical assumptions, Bohr had succeeded in deriving equations for the Balmer series and the yet-to-be-discovered Lyman series. But in 1913 hydrogen was thought to exhibit some other series for which his formula could not account. In 1896 E. C. Pickering[15] had discovered a series of lines in the spectrum of the star ξ-Puppis, every alternate line of which corresponded in frequency to a line of the Balmer series. Rydberg found that by using the Balmer formula, Eq. (6), and letting n_2 take half-integral as well as whole-integral values, the Pickering series could be described. He suggested that the series was due to a form of hydrogen found only in stars. Further, he predicted that other new series should be found which would be determined by Eq. (6) if n_1 as well as n_2 were allowed to take half- as well as whole-integral values, thus, for example,

$$\nu_n=R\left(\frac{1}{2.5^2}-\frac{1}{n_2^2}\right),\quad n_2=3,\,3.5,\,4\cdots. \tag{7}$$

In 1912, A. Fowler[16] had announced the discovery of two such series, one beginning with a line of wave-length 4686A, in a spark spectrum of a mixture of helium and hydrogen. This verification of Rydberg's prediction had established very firmly his assumption that the Pickering series was due to hydrogen.

Bohr attacked this difficulty with characteristic courage. He suggested that the lines were due to helium, not hydrogen, and this suggestion led to one of the greatest successes of his theory.

Rutherford's theory required that the neutral helium atom consist of a nucleus of charge $+2e$ and two extranuclear electrons. Bohr considered the capture of one of these electrons by the nucleus and got, since the nuclear charge is now $2e$ in place of e,

$$\nu=\frac{8\pi^2me^4}{h^3}\left(\frac{1}{\tau_2^2}-\frac{1}{\tau_1^2}\right)$$

$$=\frac{2\pi^2me^4}{h^3}\left(\frac{1}{(\tau_2/2)^2}-\frac{1}{(\tau_1/2)^2}\right). \tag{8}$$

Substitution of $\tau_2=1$ or $\tau_2=2$ gave lines in the ultraviolet region; of $\tau_2=3$, very closely two of the series that Fowler had described the year before; of $\tau_2=4$, the Pickering series, observed too by Fowler, and every alternate line of which was considered to be identical with a line of the Balmer series of hydrogen. Substitution of $\tau_2=5$ and $\tau_2=6$ should give series in the infra-red.

Since the series observed by Pickering and Fowler were not found in ordinary discharges in pure helium, Bohr suggested that his explanation required the initial removal of both electrons from the atom, and that the removal of the second electron would require much more energy than the removal of the first one; the presence of hydrogen might facilitate the process because the hydrogen atom could acquire a negative charge, a fact that had been experimentally observed in connection with work on positive-ray analysis. Experimental evidence to confirm Bohr's hypothesis came almost immediately. In August 1913, J. Evans[17] announced that he had discovered the line 4686A in a spark spectrum of pure helium, and that the hydrogen lines 6563A and 4861A had not been found. Furthermore, the line 4686A could not be obtained with either pure hydrogen, a mixture of neon and hydrogen, or a mixture of argon and hydrogen. This appeared to be conclusive verification of Bohr's theory.

Fowler,[18] however, was not satisfied. He thought that the differences between the theoretical values of some of the lines calculated from Bohr's formula and the observed values were too great to be accounted for by experimental error. The fact that Evans had not found the line 4686A under the conditions described did not preclude the possibility that it was a characteristic hydrogen, not helium, line. It might be due to residual hydrogen, and possibly would appear only in the presence of helium.

[15] Pickering, Astrophys. J. **4**, 369 (1896); **5**, 92 (1897).
[16] Fowler, Month. Not. R. A. S. **73**, 62 (1912).
[17] Evans, Nature **92**, 4 (1913).
[18] Fowler, Nature **92**, 95 (1913).

In October, Bohr[19] cleared up the matter. His formula for the Rydberg constant, he wrote, had been derived on the assumption that the mass of the electron was negligibly small compared to that of the nucleus; that is, the nucleus was assumed to be stationary. If the finite mass of the electron were not neglected, the electron and nucleus would both revolve about their common center of mass. Let the radius of the circular path of the electron about this common center of mass be a_m, the radius of that of the nucleus be a_M, the distance between electron and nucleus in the nth orbit be a_n, and the masses of the electron and nucleus, respectively, be m and M. Then, from ordinary mechanics,

$$a_m=\frac{M}{M+m}a_n,$$

$$a_M=\frac{m}{M+m}a_n.$$

The total angular momentum about the center of mass is

$$m\omega_n a_n^2\frac{M}{M+m}=\frac{nh}{2\pi};$$

hence

$$\omega_n a_n^2=\frac{nh}{2\pi}\,\frac{M+m}{mM}.$$

If the centripetal force equals the Coulomb attraction,

$$m\omega_n^2 a_n\frac{M}{M+m}=\frac{ee'}{a_n^2},$$

or

$$\omega_n^2 a_n^3=\frac{ee'}{m}\cdot\frac{M+m}{M}.$$

The kinetic energy of the system is

$$T_n=\tfrac{1}{2}m\omega_n^2a_n^2\left(\frac{M}{M+m}\right)^2$$

$$+\tfrac{1}{2}M\omega_n^2a_n^2\left(\frac{m}{M+m}\right)^2=\tfrac{1}{2}\omega_n^2a_n^2\frac{Mm}{M+m},$$

which, in view of the preceding equation, reduces to

$$T_n=\frac{ee'}{2a_n}=E_n.$$

[19] Bohr, Nature **92**, 231 (1913).

The total energy in the nth orbit is then

$$E_n=\frac{2\pi^2e^2e'^2}{n^2h^2}\,\frac{Mm}{M+m}.$$

For a transition from orbit n_2 to orbit n_1,

$$\nu=\frac{2\pi^2e^2e'^2}{h^3}\cdot\frac{Mm}{M+m}\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right). \qquad (9)$$

To check this theory, Bohr calculated the reciprocal K of the Rydberg constant from Eq. (9) for hydrogen and helium, and found the ratio between the two. Using the values $M_{\mathrm{H}}=1835m$, $e_{\mathrm{H}}'=e$, and the accepted values of h, e and m, for hydrogen, and $e_{\mathrm{He}}'=2e_{\mathrm{H}}'$, $M_{\mathrm{He}}=4M_{\mathrm{H}}$ for helium, he found the ratio of the calculated values to be

$$K_{\mathrm{H}}/K_{\mathrm{He}}=4.00163.$$

Then, using the values of the wave-lengths of the lines observed by Fowler, he found the ratio of the empirically determined values of K to be

$$K_{\mathrm{H}}/K_{\mathrm{He}}=4.0016.$$

This is an astonishing agreement between theory and observation.

Bohr further predicted that a spectral series in helium should be discovered, corresponding to $n_1=4$ and $n_2=6, 8, 10\cdots$. This series would almost coincide with the Balmer series in hydrogen. The wave-lengths should be 6560.3, 4859.5, 4338.9A$\cdots$ as compared with 6562.8, 4861.38, 4340.51A$\cdots$ for the hydrogen lines. Several years later E. Paschen[20] announced the discovery of these lines in helium, and gave the following wave-lengths: 6560.19, 4859.40, 4338.74A—another remarkable agreement of observation and theory!

However, before this work of Paschen appeared Nicholson[21] had suggested that Evans' new series and the Pickering series might be deduced from the 4686A series by means of the combination principle of Rydberg and Ritz. Therefore, the apparent verification of Bohr's theory by the experimental work of Evans was not verified.

[20] Paschen, Ann. d. Physik **50**, 901 (1916).
[21] Nicholson, Nature **94**, 642 (1915).

Bohr[22] replied that while waiting for further spectroscopic evidence, which, as has been stated, Paschen supplied the following year, he could not agree with Nicholson. He adduced two especially strong reasons: (i) Evans' work strikingly pointed out the great difference in chemical conditions required to produce, on the one hand, the lines of the Balmer series, and, on the other hand, those required to bring out the lines in question; there was no analogy for this in connection with the production of the diffuse series of the alkalis; (ii) recent work by Rau[23] on resonance potentials had shown that to get the ordinary helium spectrum, 30 v were required; the Balmer series could be obtained at 13 v, whereas the Pickering series and the 4686A series required 80 v. According to Bohr's theory, the energy needed to ionize hydrogen was 13.6 ev, to singly ionize helium 29.0 ev, and to doubly ionize helium, 83.4 ev.

5. SPECTRA OF OTHER HYDROGEN-LIKE ELEMENTS

Bohr's deductions had successfully accounted for the spectral series of hydrogen and singly ionized helium. This fact suggested that any element whose atom could assume a hydrogen-like structure, consisting of a nucleus of charge Ze with one electron revolving about it, should give rise to spectral series that would be described by the equation,

$$\nu=\frac{2\pi^2\mu e^2e'^2}{h^3}\left(\frac{1}{\tau_2{}^2}-\frac{1}{\tau_1{}^2}\right), \quad (10)$$

where μ replaces $Mm/(M+m)$ in Eq. (9). The only elements that come into consideration in this connection besides helium are the next two in the periodic table, lithium and beryllium, whose nuclei have charges of $3e$ and $4e$, respectively.

The lithium atom becomes hydrogen-like when it loses two of the three electrons which it possesses in the normal state. If the atom in this doubly ionized condition is excited, the remaining electron will experience a transition between two stationary states, and the frequency of the resulting radiation would be given in this case, since $e'=3e$, by

$$\nu=\frac{2\pi^2\mu e^4}{h^3}\left(\frac{1}{(\tau_2/3)^2}-\frac{1}{(\tau_1/3)^2}\right). \quad (11)$$

For a check of this prediction only one piece of experimental evidence was available. Nicholson[24] had observed, in the spectra of some stars that gave a very intense Pickering series, certain lines whose frequencies could be expressed by the empirical formula,

$$\nu=R\left(\frac{1}{4}-\frac{1}{(n\pm 1/3)^2}\right), \quad (12)$$

where R is the Rydberg constant for hydrogen. Nicholson ascribed these lines to hydrogen. Bohr suggested they were due to doubly ionized lithium. If, in Eq. (11), one substitutes $\tau_2=6$ and $\tau_1=10$, one gets Nicholson's empirical Eq. (12) with n equal to 3. Substitution of $\tau_2=6$ and $\tau_1=13$ gives Eq. (12) with n equal to 4, while $\tau_2=6$ and $\tau_1=14$ gives Eq. (12) with n equal to 5, where the minus sign is used in the second denominator in the last case. These values of n and the corresponding values of τ gave the lines observed by Nicholson. It is interesting to note that setting $\tau_2=3$ and $\tau_1=6$ in Eq. (11) gives a line of wave-length 135.02A found in 1930 by Ericson and Edlèn[25] in the spectrum of doubly ionized lithium.

Beryllium, with a nuclear charge of $4e$, will become hydrogen-like if three of its four electrons are removed. Equation (10) will then become

$$\nu=\frac{2\pi^2\mu e^4}{h^3}\left(\frac{1}{(\tau_2/4)^2}-\frac{1}{(\tau_1/4)^2}\right). \quad (13)$$

A line of wave-length 75.94A corresponding to the frequency given by Eq. (13) if $\tau_2=4$ and $\tau_1=8$ was also discovered by Ericson and Edlèn in 1930.

6. ATOMS CONTAINING LARGER NUMBERS OF ELECTRONS

The next step, the explanation of the spectra of elements of higher atomic number, led to the

[22] Bohr, Nature **95**, 6 (1915).
[23] Rau, Sitzungsber. d. Phys. Med. Ges. Wurzburg (1914).
[24] Nicholson, Month. Not. R. A. S. **73**, 382 (1913).
[25] Ericson and Edlèn, Zeits. f. Physik **59**, 679 (1930).

usual difficulties that are encountered whenever the interaction of more than two bodies is considered. Here again Nicholson had done a great deal of preliminary work. In the afore-mentioned series of papers published by him in 1912 he had worked out stability and equilibrium conditions for several configurations of a model that consisted of a central nucleus about which a ring of electrons revolved. The "nebulium" atom with a ring of four electrons has been mentioned.[26] He concluded that the spectra might be explained by considering the result of slightly displacing these electrons from their orbits. They would then vibrate about their original orbital positions and emit radiation of a frequency equal to their vibration frequency. He found, from his application of mechanics, that this system would be stable for oscillations perpendicular to the plane of the orbit, but would be unstable for oscillations in the plane itself. This was the status of the dynamics of the nuclear atom model for larger numbers of electrons when Bohr took over.

One ring, with p electrons.—Using Nicholson's calculations,[27] Bohr applied his theory as follows. Consider an atom with p electrons in the ith ring orbit. If these electrons jump to a ring farther in, radiation will be emitted. Assuming the center of mass of the system to be at the center of the nucleus, and also the orbital velocity of the electrons to be small enough so that one does not have to introduce a relativity correction or consider the magnetic effect of the rotation of the electrons, he treated the problem as follows.

(i) The condition of stability was taken to be that $ma_i^2\omega$, the angular momentum of each electron, is equal to $ih/2\pi$.

(ii) Consider a ring of radius a_i. A given electron is acted on by the attractive force of the nucleus and the repulsive effect of the other $p-1$ electrons. The angle formed by the radius of electron "p" and the radius to the sth electron from it is given by $s\cdot 2\pi/p$. The distance of s from p is $2a \sin s\pi/p$. The component, in the direction of the radius, of the force exerted by s on p is

$$\frac{e^2}{4a_i^2}\frac{1}{\sin\,(s\pi/p)}.$$

The total force of repulsion on p due to all the other electrons will therefore be

$$\frac{e^2}{4a_i^2}\sum_{s=1}^{s=p-1}\frac{1}{\sin s\pi/p}.$$

If we let

$$S_p=\frac{1}{4}\sum_{s=1}^{s=p-1}\frac{1}{\sin s\pi/p},$$

the total electrostatic force F on the pth electron is

$$F=\frac{e}{a_i^2}(e'-S_pe),$$

where e' is the charge on the nucleus. Equilibrium is maintained if the required centripetal force equals the electrostatic force F; that is, if

$$\omega_i^2a_i^3=(e/m)(e'-S_pe), \tag{14}$$

where ω is the angular speed of the electrons.

(iii) From these two conditions we get

$$a_i=\frac{i^2h^2}{4\pi^2me}\frac{1}{e'-S_pe}$$

and

$$\omega_i=\frac{8\pi^3me^2(e'-S_pe)^2}{i^3h^3}. \tag{15}$$

(iv) *Energy condition.* Consider the electrons initially at rest at infinity. Insofar as the attractive force of the nucleus on the ring is concerned, the potential energy of the system is zero; but the ring itself, owing to the mutual repulsion of the electrons, has potential energy given by

$$\frac{pe^2}{4a_i}\sum_{s=1}^{s=p-1}\frac{1}{\sin s\pi/p}=pS_pe^2/a_i.$$

If the electrons now move into the ith ring orbit, they will lose potential energy, owing to the attraction of the nucleus. This loss in energy is equal to pee'/a_i. The total potential energy of the system now is

$$U_i=\frac{pS_pe^2}{a_i}-\frac{pee'}{a_i}.$$

The kinetic energy of the system is

$$T_i=p\cdot\tfrac{1}{2}m\omega_i^2a_i^2$$

[26] Reference 1, sec. 5.

[27] Nicholson, Month. Not. R. A. S. **72**, 49, 139, 677 (1911–12).

or, in view of Eq. (14),

$$T_i = p \cdot e/2a_i(e' - S_p e).$$

The total energy of the system of ring and nucleus is thus

$$E_i = U_i + T_i = \frac{pS_p e^2}{2a_i} - \frac{pee'}{2a_i} = \frac{pe}{2a_i}(S_p e - e'),$$

or, using the value for a_i given by Eq. (15),

$$E_i = \frac{p \cdot 2\pi^2 me^2(e' - S_p e)}{i^2 h^2}. \tag{16}$$

This energy will be radiated by the system, as in the case of the single electron.

If all the electrons in the ring simultaneously drop from ring k to ring i, the energy liberated as a result of the transition would be

$$E_k - E_i = \frac{p \cdot 2\pi^2 me^2(e' - S_p e)^2}{h^2}\left(\frac{1}{i^2} - \frac{1}{k^2}\right).$$

The frequency ν_{ik} of this radiated energy is given by $E_k - E_i = ph\nu_{ik}$, since each electron has energy $h\nu_{ik}$. Hence

$$\nu_{ik} = \frac{2\pi^2 me^2(e' - S_p e)^2}{h^3}\left(\frac{1}{i^2} - \frac{1}{k^2}\right). \tag{17}$$

Bohr thus arrives at an equation for the frequency of a spectral line for an element with p electrons analogous to the hydrogen formula and differing from it only in that the nuclear charge is replaced by $e' - S_p e$, the "effective" nuclear charge. The quantity $S_p e$ was called the ***nuclear defect***, and was subtracted from e' to allow for the repulsive effect of the electrons upon one another. At the time when Bohr published this discussion, an experimental test was still lacking. It was made shortly afterwards.

Several rings.—Bohr worked out a tentative, quite sketchy mathematical theory for the case of several rings and discussed the topic qualitatively. He suggested that the electrons, when captured by the atom, will tend to coalesce into rings, which will be stable provided the electrons are considered to be discrete and symmetrically placed in the rings. The electrons would have constant angular momentum, and the whole system would be stable if the electrons were disturbed only in a plane perpendicular to their orbital plane. From considerations of stability Bohr shows that if the charge on the nucleus is not too large, one should expect to find an even number of electrons in an inner ring. If there is an odd number of electrons in the atom, the arrangement will obey this requirement, thus forcing the odd electron to occupy another ring; for example, lithium would have two electrons in the inner ring and a third in an outer ring. In the case of beryllium there would be two electrons forming an inner ring and then two more in an outer ring. He states this despite the fact that an atom in the normal state is in the state of lowest energy and the total energy for the beryllium atom with four electrons in the inner ring is less than that for the afore-mentioned configuration. These considerations, and the chemical evidence as illustrated in the periodic table with its periodicity of eight, led Bohr to his first formulation of the *Aufbauprinzip.*

The Aufbauprinzip.—Bohr concluded that each element in the periodic table may be thought of as built up from the preceding one by the addition of one electron to the extranuclear region and of an equal positive charge to the nucleus. When a ring was completed, a new one would be formed. Helium would have a closed ring of two electrons; lithium a ring of two electrons with one electron outside; beryllium two rings of two electrons each; and so on. To illustrate the theory, and to show how it contrasts with the viewpoint held generally today, the data in Table I are reproduced from Bohr's second paper.

TABLE I. Arrangements of electrons in atoms 1 to 24.

Atomic number	Electrons	Atomic number	Electrons	Atomic number	Electrons
1	1	9	4, 4, 1	17	8, 4, 4, 1
2	2	10	8, 2	18	8, 8, 2
3	2, 1	11	8, 2, 1	19	8, 8, 2, 1
4	2, 2	12	8, 2, 2	20	8, 8, 2, 2
5	2, 3	13	8, 2, 3	21	8, 8, 2, 3
6	2, 4	14	8, 2, 4	22	8, 8, 2, 4
7	4, 3	15	8, 4, 3	23	8, 8, 4, 3
8	4, 2, 2	16	8, 4, 2, 2	24	8, 8, 4, 2, 2

The configuration of the electrons in the rings for elements of atomic numbers 1 to 24 are given, the innermost ring being represented by the number on the left.

This part of Bohr's theory was severely criticized by Nicholson.[28] He wrote that while it was universally assumed that the atom of an element can form a Saturnian system with more than one ring of revolving electrons, such an arrangement actually was impossible. If the law of repulsion between two electrons, or of attraction between an electron and a nucleus, is that of inverse squares, two or more coplanar rings cannot exist; all the electrons in any plane must lie in the same ring. Even if the rings are in different planes the radii of the rings must be nearly equal. Since Bohr's theory assumes that the mathematical expression for the steady rotation of the system can be derived by ordinary mechanics, and the equation so derived is vital to his formula for spectra, the idea of coplanar rings would have to be abandoned. Bohr did not reply to this, and there is no evidence in his writings up to 1916 that he tried to develop further this part of his theory.

7. X-RAYS

Bohr's early theory.—Bohr sought the chief verification of his theory concerning coplanar rings of electrons in an explanation of the origin of x-rays. By 1913 the great work accomplished by Barkla in the decade just finished had furnished a good picture of the phenomenon of x-ray emission. The radiation was probably due to disturbances of the inner electrons of the atoms, and the total number of electrons in an atom was about half the atomic weight. Bohr restrained himself, in his first paper, from making any assumptions as to the nature of x-rays. He was content to point out that since an optical spectrum is produced when one or more electrons of the *outer rings*, having been removed, return to stationary orbits, so by analogy, a characteristic x-radiation might be emitted when a system returned to its normal energy state, after electrons in the *inner rings* had been removed—perhaps by the impact of cathode particles. It would not be possible to calculate the exact energy required to liberate an electron from a given ring without making further assumptions; but one could get an approximation by neglecting the nuclear defect.

The velocity of the electron would be given by

$$v=2\pi Ze^2/h=2.1\times10^8Z,$$

where Z is the number of electrons in the atom. The total energy needed to remove this electron from the atom is equal to the kinetic energy of this electron when bound. Hence the minimum energy of an impinging cathode particle required to remove this electron from the atom must be equal to the energy of the electron. Whiddington's[29] experiments had demonstrated that the speed of cathode particles which are just able to produce characteristic x-rays of the highest frequency—Barkla's K radiation—from an element of atomic weight A, ranging from aluminum to selenium, is about $A\times10^8$ cm/sec. This is nearly equivalent to Bohr's figure, if $Z=\frac{1}{2}A$. Bohr considered it worthy of note that his theory gave very nearly the correct value for both the energy required to remove an electron from an outer ring and for the energy needed to remove one from the innermost ring. For an element of atomic weight 70 these two energies differed by a ratio of 1000 to 1. A further check was afforded by a calculation of atomic radii. For an element of atomic weight 100 the radius of the inner ring would be about 10^{-10} cm.

Moseley's experiments and the Bohr theory.—The classic papers of H. G. J. Moseley[30] on "High frequency spectra of the elements" came a few months after the appearance of Bohr's first paper. Moseley found lines that could be classified into two groups: (i) a group with shorter wave-lengths, corresponding to Barkla's "K" characteristic secondary radiations, and (ii) a group with longer wave-lengths, corresponding to Barkla's "L" radiation. He found also that, unlike the optical spectra, the characteristic x-ray spectra of the elements were similar from element to element, homologous lines occurring, in general, at shorter wave-lengths as the atomic weight of the element in which the lines originate increased. For the strongest line of the K radiation Moseley discovered that the frequency in the case of a large number of elements ranging from Al ($Z=13$) to Ag ($Z=47$) was given with a con-

[28] Nicholson, Phil. Mag. **27**, 562 (1914)

[29] Whiddington, Proc. Roy. Soc. **A85**, 323 (1911).

[30] Moseley, Phil. Mag. **26**, 1024 (1913); **27**, 703 (1914).

siderable degree of accuracy by the empirical formula,

$$\nu=0.248\times10^{16}(Z-1)^2,$$

where Z is the atomic number. He compared this formula with Bohr's formula for the hydrogen spectrum, and on substituting $\tau_2=1$ and $\tau_1=2$, found that it becomes

$$\nu=\tfrac{3}{4}Z^2R,$$

where R is the Rydberg constant as given by the Bohr theory. Therefore, except for the slight change in Z, his empirical formula was almost identical with Bohr's equation. Moseley's explanation of the presence of the factor $Z-1$ instead of Z was based on the equation derived from Bohr's theory of a ring of electrons,

$$\nu_{ik}=R\left(\frac{e'}{e}-S_p\right)^2\left(\frac{1}{i^2}-\frac{1}{k^2}\right).$$

If we substitute Z for e'/e, we get

$$\nu_{ik}=R(Z-S_p)^2\left(\frac{1}{i^2}-\frac{1}{k^2}\right).$$

Since $S_p=0.957$ if $p=4$, Mosely assumed that there were four electrons in the inner ring, and suggested that this ring underwent a transition between two states in which the angular momentums were $2h/2\pi$ and $h/2\pi$, respectively.

Bohr[31] disagreed with this, pointing out that the agreement of his theory with Whiddington's measurements of the energy required by a cathode particle to produce secondary characteristic radiation signified very clearly that the spectra observed by Moseley originated in the removal and subsequent return of a single electron and not of a whole ring. If the latter were true, the energy required would have to be several times as large as was found to be the case. He considered that not enough was known about the subject to permit a detailed explanation of Moseley's results.

Nicholson[32] in his paper attacking Bohr's idea of coplanar rings had also pointed out that Moseley's assumption would involve the emission of several quanta, which was not the case in the explanation of other phenomena. He concluded that Moseley's experiments did not in the least support Bohr's theory. In this view he was supported by F. A. Lindemann[33] who found in Moseley's results verification of the theories of Rutherford and van den Broek, but not of those of Bohr. Lindemann based his criticism on a dimensional analysis of the quantities involved, and attempted to show that the relation between the wave-length and the positive charge can be derived in a large number of ways. Bohr[34] replied that all of Lindemann's expressions became identical if it were admitted that the quantities ν, a, Ze^2, m and h are not independent of one another, which could be shown to be the case; and that, on the other hand, one could not calculate the numerical factors from dimensional analysis alone, but in order to compute frequencies, would have to introduce more detailed assumptions as to the constitution of the atom and the mechanism of emission of radiation. In the same paper Moseley also replied that despite Nicholson's and Lindemann's opinions, Bohr's formula was the only one of the "h" hypotheses, presented by Nicholson, Bohr and J. J. Thomson, that was supported by his experimental evidence. He realized that it was difficult to see how a ring of four electrons could store up enough energy to vibrate as a whole; and also that Bohr's theory failed to account for the second weaker line found in each spectrum.

Kossel's theory.—Further support for Bohr's theory of coplanar rings came almost immediately after Moseley's work through the very important and interesting developments of W. Kossel.[35] He adopted the nuclear atom and assumed with Bohr that the electrons were arranged in rings about the nucleus, one ring inside another. All radiation from the atom is due to transitions of the system from one energy level to another, and the frequency of the radiation is E/h. He considered the case in which one electron is removed from the atom and then radiates as it returns to its original condition. The return can take place in several ways. The place in the ring vacated by

[31] Bohr, Phil. Mag. **27**, 394 (1915).
[32] Reference 27, Phil. Mag. **27**, 562 (1914).
[33] Lindemann, Nature **92**, 500 (1914).
[34] Bohr, Nature **92**, 583 (1914).
[35] Kossel, Verh. d. D. Phys. Ges. **16**, 953 (1914).

the electron can be filled by the same electron returning to it; or by an electron from an outer ring whose place, in turn, could be filled by an electron from outside or from a ring still farther out, and so on. Kossel suggested that the K radiation occurs when an electron removed from ring 1 (nearest the nucleus) returns to this ring, and developed the hypothesis that the spectral line called $K\alpha$ by Moseley corresponds to the radiation emitted when an electron drops from ring 2 to ring 1; $K\beta$ to the radiation emitted when an electron drops from ring 3 to ring 1. This implies that the K radiation spectrum consists of the same number of lines as the atom has rings, and that the lines form a series of rapidly increasing intensity. The L radiation was explained analogously by assuming that an electron is removed from ring 2, and that one from ring 3, $4 \cdots$ takes its place. A possible M radiation was ascribed to the third ring.

A very significant feature of this theory is that it predicts a number of simple relations between the frequencies of various lines. Thus an immediate conclusion from the theory is that

$$\nu_{K\beta} - \nu_{K\alpha} = \nu_{L\alpha},$$

$$\nu_{K\gamma} - \nu_{K\beta} = \nu_{L\beta} - \nu_{L\alpha} = \nu_{M\alpha}.$$

These equations correspond exactly to the ordinary combination principle for spectral lines. Using Moseley's values for the frequencies of $K\alpha$ and $K\beta$ and extrapolating for that of $L\alpha$ by use of his empirical formula, Kossel showed that there is experimental evidence for his conclusions. This was strengthened by Bohr, who used more recently obtained measurements made by T. Malmer[36] on the wave-lengths of the $K\alpha$ and $K\beta$ lines of elements whose atomic numbers exceeded those of the elements on Moseley's list. The values checked very closely.

Bohr adduced a further point. If radiation corresponding to the line $K\alpha$ is emitted by the transition of an electron from ring 2 to ring 1, the absorption line of this frequency should result when an electron passes from ring 1 to ring 2. Since this could not happen if ring 2 already contained its maximum allowable number of electrons, it would be necessary to make a vacant place in ring 2 for the inner electron to occupy. This means that no absorption will occur unless sufficient energy is supplied to remove the electron from ring 1 to the surface of the atom. This hypothesis was confirmed by the experimental work of Bragg,[37] who found that no radiation corresponding to any of the K lines is emitted unless the value of $h\nu$ of the exciting radiation exceeds the limit of the K series. When this happens, however, *all* the K lines appear. Another conclusion from Kossel's theory would be that it is not possible to have K-series radiation without a simultaneous emission of the L series. For, by assuming Bohr's second postulate to apply to absorption as well as emission, Kossel's relations would give the following result.

Let ν_{K_g} be the absorption frequency corresponding to the removal of an electron from the K ring to the surface of the atom, and ν_{L_g} the corresponding quantity from the L ring. Then

$$\nu_{K\alpha} - \nu_{K_g} = -\nu_{L_g}.$$

Some data supplied by Barkla[38] concerning the quantity of energy used to excite characteristic x-ray radiation appeared to verify this conclusion.

At this time A. H. Compton and Bragg[39] stated that Bragg's data on the scattering of x-rays from rocksalt afforded the conclusion that the intensities of the different orders could not be accounted for by assuming the atoms to be made up of single rings of electrons, or by assuming a uniform volume distribution of the electrons in spheres. The distribution that fitted Bragg's data acceptably would be an arrangement of the electrons in equally spaced concentric rings, each ring having the same number of electrons.

8. CONCLUSION

We have seen that the theory of the atom presented by Bohr was found competent to explain the emission of the spectra of hydrogen, helium, and stripped lithium and beryllium atoms. Moseley, Bohr and Kassel had successfully applied the theory to explain x-ray spectra. The

[36] Malmer, Phil. Mag. **28**, 787 (1914).

[37] Bragg, Phil. Mag. **29**, 407 (1915).

[38] Barkla, Nature **95**, 7 (1915).

[39] Compton and Bragg, Nature **95**, 343 (1915).

theory had also provided a great stimulus for further research both in the theoretical and experimental aspects of the field of atomic physics.

Bohr went much farther than this, however. In these early years of his endeavor he attacked the theoretical problems presented by the experiments on absorption of energy by atoms carried out by Lenard and by Franck and Hertz, and also the explanation of the Zeeman and Stark effects on the basis of the quantum theory. In addition, he began from the very start to develop his famous *correspondence principle*, which occupied such a prominent place in atomic theory prior to the birth of quantum mechanics. These phases of Bohr's early work will be discussed in the third, and final, article of this series.

Physics at Trinity College*

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TRINITY College, a small New England liberal arts college for men, has a population of 550 to 600 students in normal times. The physics department is housed in the Jarvis Hall of Science. Erected in 1887, this building was probably one of the first in the country to be designed with laboratory space and lecture rooms for the exclusive use of a physics and a chemistry department—the basement and first floor for physics, the second floor for chemistry. In 1936 the chemistry department moved into a new building of its own, and physics was given the use of the entire building. Plans for fairly extensive alterations were considered, but it was decided that the cost would not be warranted. So the principle alterations were those necessary to change from chemistry to physics furniture in the laboratories. We now have adequate laboratory and office space—and do not suffer from attacks by gases or liquids! It does not seem profitable to describe the floor plans of an old building, but one feature of the renovations has proved so satisfactory that it might be of interest to others. The old general chemistry laboratory was a large room, in fact the largest laboratory in the building, so it was made over for a first-year physics laboratory. However, rather than use the whole room, one end was walled off and made into four "cubicles," each large enough to house an experiment. These rooms are used especially for certain experiments in sound and light, or whenever outside disturbances would interfere with the work in progress. We have recently had a large basement room renovated and equipped for use as a laboratory by the students admitted at the middle of the college year. The laboratory tables are not of uniform design, but the room is proving to be very serviceable.

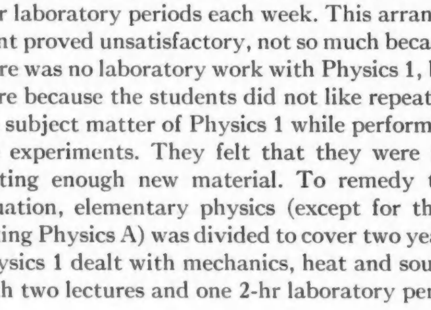
Probably of more interest are the courses we give, their organization and the numbers of students electing them. At this point it might be well to remark that we do not believe in using cheap apparatus in any laboratory courses, not even from the start. For instance, in the very first experiments performed, use is made of machinist rules, vernier micrometers and vernier calipers. It has been our experience that the respect for and interest in an experiment seems to be governed mainly by the accuracy which is attainable, and cheap apparatus more frequently than not is inaccurate. This does not mean, of course, that if a hairpin and a tin can suffices for a certain purpose, a student is discouraged from utilizing them.

Our college bulletin lists the following courses as offered: Physics A, 1, 2ab, 3ab, 4ab, 5, 6ab, 7b, 8, 9b. An "a" means that the course is given in the first semester; a "b," in the second semester.

* This article is one of a series intended to acquaint readers with physics buildings, equipment and instructional procedures at various institutions. For a list of other articles in the series, see Am. J. Phys. **10**, 102, 307 (1942).

Physics A, 1 and 2 have had interesting histories. About 25 years ago Physics A was a first course given to all men electing physics who had not received credit for physics on admission. It was a sort of glorified high school course in which a high school text was used and very simple experiments were performed. About 1920 agitation arose on the part of certain of the "arts" faculty for a course to cover the "cultural" aspects of physics with no student laboratory, a terminal course that, oddly enough, was to count as a laboratory science for certain language majors. By this time it was evident that a man who took the "baby" course and wanted to continue in the physical sciences or engineering might as well have begun with the next course, first-year college physics. So Physics A became an "arts" course in physics meeting three times each week, with many demonstration experiments, but no experiments performed by the student. It counted as a laboratory science for certain students, but only as a science for others.

Physics 1, first-year college physics, met three times a week but, like Physics A, had no laboratory. Physics 2 was really the laboratory course for Physics 1; it involved one lecture and two 2-hr laboratory periods each week. This arrangement proved unsatisfactory, not so much because there was no laboratory work with Physics 1, but more because the students did not like repeating the subject matter of Physics 1 while performing the experiments. They felt that they were not getting enough new material. To remedy this situation, elementary physics (except for those taking Physics A) was divided to cover two years. Physics 1 dealt with mechanics, heat and sound, with two lectures and one 2-hr laboratory period each week. Physics 2 was merely a continuation of Physics 1, with light and electricity as the subject matter. Thus two years were required with 12 semester-hours credit for what is ordinarily called first-year college physics. This arrangement was quite satisfactory from many standpoints. Certainly the students learned considerable physics. But the premedical students objected to 12 semester hours when only eight were required by the medical schools. In addition, students in general did not feel that they were advancing rapidly enough; they did not respond enthusiastically to using the same textbook for two full years. Consequently, another change was made that brings us to the present Physics 1 and 2ab.



Jarvis Hall of Science, now usually called Jarvis Physical Laboratory.

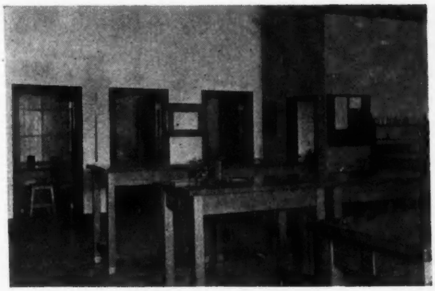
Physics 1 is an eight semester-hour course with three lectures and one 2-hr laboratory period per week for one year. All men electing first-year college physics take this course, regardless of whether or not they received credit for physics on entrance. We find little difference in grades between the two groups. In fact, each time that I have checked the two groups (and this system has been in operation about 10 years), those men who did not have physics before had a higher average as a group, but the difference was small. What seems to make much more difference in grades is whether or not a student has taken in high school all the mathematics he could or merely the minimum for college entrance. Using mathematical ability as a criterion of probable success in physics seems to be so good that in the future (in normal times, at least) we shall doubtless require all men registered for Physics 1 to take a "placement" examination in mathematics during the opening week of college. Those who fail will not be allowed to elect physics until after completing the freshman course in mathematics.

Physics 2ab is really two half-courses of three semester hours each; 2a covers physical optics, two lectures and one 2-hr laboratory period each week for one semester; 2b is a corresponding course in electricity and magnetism. In freshman mathematics the elements of differential and integral calculus are studied, so we use the calculus freely in 2ab. All the men taking Physics 2ab also take a second course in mathematics which reinforces their knowledge of the calculus. Students respond nicely to this course because

they feel that they are definitely progressing beyond Physics 1.

While these changes were taking place in Physics 1 and 2, Physics A had remained unchanged. The number of students taking the course fluctuated between 10 and 20. In 1936 there was a change of attitude on the part of those faculty members who previously had not wanted student laboratory included. The feeling prevailed, however, that a course should still be offered primarily for arts students, one not as stiff as Physics 1. To meet this demand, the course was changed to two lectures and one 2-hr laboratory period each week. The elections dwindled immediately, so much so that the course was discontinued after three years. This experience certainly indicates that most of the men taking this course did so because no laboratory work was required. With the present loss of departmental manpower and with war training programs to consider, there has been little time to reflect on what to do with Physics A. However, at the risk of being regarded a heretic for even considering an elementary physics course without accompanying laboratory work, I believe I am ready to assert that such a course will attract students who can be reached in no other way and will give them sufficient acquaintance with the subject matter of physics to make it worth while for all concerned. Perhaps our elementary courses are too frequently taught with the notion, no doubt unconscious, that all the students are going to be physicists.

For a number of years the registration in Physics 1 has been between 80 and 120 men, mostly freshmen. The percentage of the student body taking this course is so large because we operate on a group system and all predental, premedical and preengineering students as well as all biology, chemistry, mathematics and physics majors are required to take it as freshmen. The number either dropping out or failing is fairly large. Owing to scheduling difficulties the group is divided into two parts for lecture demonstration and into sections of no more than 20 men for problem and discussion periods as well as for laboratory work. There are 15- to 20-min written quizzes each week. In the laboratory we use mimeographed sheets which give instructions in more or less "cookbook" fashion. The men work



A portion of one first-year laboratory showing the "cubicles."

in pairs for most of the experiments. One staff member and a student assistant are present throughout the laboratory period and circulate among the men asking questions and endeavoring to correlate experimental work with the classroom work. The experiments must be written up and handed in at the following laboratory period. This course is also given in the evenings by the extension department and in the summer school.

Physics 2 elections vary from 30 to 40, so the men are divided into two sections. Each week these sections meet together once, separately once for classroom and also once for laboratory work. Instead of weekly quizzes, a full hour test is given every three or four weeks. The laboratory is conducted as for Physics 1. Occasionally students become so inquisitive along certain lines that they are allowed to be more or less "on their own" on an experiment which supplements but does not replace the regular experiments.

I have written in considerable detail about courses A, 1 and 2ab because I suspect that they are the "headaches" for others as they have been for us. So I shall only briefly sketch the other courses.

Physics 3ab is a full year course in *Analytical mechanics*, meeting three times each week. Elections vary from 10 to 20. The course is open to sophomores but is usually elected only by juniors and seniors. There is no laboratory work. Men taking this course get a thorough training in this very fundamental branch of physics.

Physics 4a is a course in *Advanced electricity and magnetism* in which alternating-current theory and some electronics are introduced. Meetings are held twice each week for lectures

One corner of a large basement room renovated and equipped for use as an additional first-year laboratory.

and once for laboratory. Elections vary from 6 to 15. A textbook is used, and the experiments are outlined in this book. The emphasis is on laboratory work so the men are left much more to themselves and are expected to determine the limitations of the experimental procedure for the apparatus used in an attempt to wean them from "cookbook" habits. The students soon learn that supplementary reading is advisable.

Physics 4b is a half-year course in *Electrical engineering*. Most of the men who take 4a continue with 4b. Laboratory facilities limit the class to 12 men. Meetings are as for 4a. The laboratory work is of an engineering character and involves both direct- and alternating-current machinery. To the best of my knowledge, every student has been enthusiastic about the laboratory work in this course, perhaps partly because he dirties his hands and dismantles machinery. Or it may be that the enthusiasm is due to the fact that the apparatus is large and of obvious commercial utility.

Physics 5 is a six semester-hour course in *Theoretical physics* given in alternate years and only to 5 to 10 students, mostly seniors, who have shown a real aptitude for mathematics.

Physics 6a is a three semester-hour course in *Modern physics*. Elections have varied from 6 to 16. Some years a textbook is used with supplementary reading required. More usually, however, it is a lecture course because our aim is to get the students acquainted with the literature of various specialized fields and in the habit of at least looking in journals for current reports on research.

Physics 6b is a three semester-hour course in *Advanced laboratory*. For a few weeks there are one lecture and two laboratory periods, after that there are three laboratory periods. The nature of the course limits the enrolment to 10, and elections usually run to this limit. The students perform a large number of experiments in mechanics, heat and sound during the first part of the course. During the second part the experiments deal with material studied in course 6a: e/m, charge on the electron, x-ray absorption, Laue spot diffraction, and so forth. Though regular hours are assigned, the men are allowed to work at their pleasure—and it pleases them to put in many extra hours.

Physics 7b, a half-year course in *Electronics*, has not been offered for three years. It was in the process of development when we dropped it in favor of Physics 8. It will probably be developed into a full-year course after the war to replace Physics 8.

Physics 8 is a course in *Radio* that is open to men who have taken Physics 1. It is a war course designed to prepare men to be radio technicians who know something about the physics of radio. In normal times we prefer to avoid a course called "radio" because men might be attracted to it who wished to do nothing but build and tinker with radio sets. Hence, we ordinarily include radio in the electronics course, the prerequisites for which are so chosen that the students will come with a good background in mathematics and physics. Both Physics 7b and 8 meet twice per week for class work and once for laboratory. The elections for 7b were from 6 to 12. Physics 8 this year was elected by 24 men, most of whom are in one of the Armed Forces reserves.

Physics 9b was introduced as a communications course; but the content is determined by the instructor, so it may be a course in ultra-high frequency, for example. Few men, perhaps five each year, are qualified to do the work.

In addition to the courses mentioned, we occasionally allow men to major in physics for a master's degree. Most of the work is then experimental. However, we have always felt that if a man was of graduate caliber, he should go to a university immediately upon receiving his baccalaureate degree. We are so busy with undergraduate work and with our own research that we are unable to give graduate students the attention to which they are entitled. A large propor-

tion of our physics majors have gone to graduate school. A few go directly into teaching or into industry. Six of our graduates are now on the staff of a prominent government-sponsored war research project.

A student majoring in physics is required to take a minimum of four courses in physics, three in mathematics (one of which must be advanced calculus or differential equations) and one in chemistry, in addition to so-called "degree requirements." Since most students who style themselves mathematics majors also fulfill the requirements for a major in physics, it is difficult to say how many graduates each year have satisfied the latter requirements. Those who declare themselves specifically as physics majors vary from 4 to 6 out of a graduating class of 100 to 120.

I have told you the story about physics at Trinity College, not because we have solved a problem, not even our own, but rather because it gives the type of information I should like to have regarding the courses and problems of other physics departments.

Bats and the Scientific Method

John Mills
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"LAW," she said, "is that which brings order out of chaos." Such was the answer I received to the question, "what do you mean by the words, *a physical law?*" The scene was a classroom in physics in a college for women; the time was a few weeks after the course started—and that was almost 40 years ago. Realizing that the answer came from a background training in the catechism of Scotch Presbyterianism, I dodged and rephrased the question. I was in search of a generalization that covered alike the law of falling bodies, Newton's third law of motion, the second law of thermodynamics and the law of universal gravitation. (This was before the days of relativity, quantum theory and nuclear atoms, and at a time when few physical constants were known beyond four significant figures.) I felt that the clear concept of *a law of nature* had a basic importance in human thought.

Of perhaps broader importance is the idea of *scientific method*. How unfortunately ignorant of that method are many who have not had the advantage of scientific training! How frequently a more scientific approach to present-day problems might be possible and certainly desirable! How can we give to layman or businessman and to the beginner in physics some idea of what we mean by scientific method?

Stripped to essentials, what we glibly call the method of science is a process of controlled experimentation whereby can be derived a quantitative relationship between the variables in a physical phenomenon; relating, for example, as Galileo was the first to do, the distance through which a body will fall and the time during which it falls. The experimenter varies only one condition at a time in order to be able to say: "*Other things being equal*, a change of so much produces such an amount of effect." Only under those conditions does he assume to draw a valid conclusion. In most of the experiments of modern science the expensive, time-consuming task is this elimination of any irrelevant and uncontrolled factors.

To the layman *science* usually means mixing things in a test tube, and *research*, cut and try. The importance of the words "all other things being equal," which are basic to the scientific method, is usually unappreciated. How can we get across to laymen, as occasion arises, some adequate concept of the scientific method? Concrete illustrations are usually needed in such a popularized exposition. The falling-body experi-

ments of Galileo, just mentioned, or the magnetic experiments of Gilbert with his terrella, are not satisfactory illustrations because they are neither modern nor timely and are slightly pedantic.

The other day, however, I came across an excellent illustration, which seems to have all the necessary characteristics. It is up to date, deals with a previously baffling phenomenon of common observation, and has analogies of practical importance. It seems an ideal illustration, to be easily grasped by high school students and probably by most laymen. It is the research of two Harvard biologists on the question of how flying bats avoid obstacles, and is reported by one of the researchers, Robert Galambos, in an article entitled, "Flight in the Dark: A Study of Bats."[1]

Do bats acquire their flight instructions through the sense of hearing? To answer, the experimenters compared the flight of bats before and after tampering with their aural mechanisms. A bat, with its ear flaps sewed down, or with a coating of wax on its eardrum, was found to be markedly less capable of avoiding obstacles. Now here comes the first important illustration of the scientific method—of the meaning of "other things being equal." Is a deafened bat's inability to avoid obstacles due to the fact that he cannot hear or to the fact that he is physically and emotionally upset by the tampering with his ears? The experimenters ingeniously arranged that other things should be equal by testing their bats first without any interference with their hearing; second with small tubes inserted in their ears, under which conditions their ability to avoid obstacles was found to be unimpaired; and finally with the tubes blocked, in which case their ability was markedly impaired. The conclusion was that hearing was essential to the avoidance of obstacles.

Now what did the bats hear and where did the sounds originate? They found that the bats uttered complex sounds (analogous to those of a human larynx) which contained component tones about two octaves above the human pitch-limit of hearing. They observed these tones by a supersonic pick-up apparatus in which a microphone converted them into electric current which, after amplification, could be analyzed for component frequencies.

Then the question was: Where did those sounds originate? Did they come from the mouth of the bat or from vibrations of other parts of the body? Submerging a bat, except for his or her head, made no difference in the sounds that were picked up except, of course, for any greater intensity and frequency of utterance occasioned by the bat's discomfort.

The scientific method thus proved that bats avoid obstacles by virtue of their aural perception of the high-pitched sounds which they utter. Incidentally, the mechanical design of the animal's larynx confirms these observations, since it is such as might be expected to give rise to high-pitched tones. Incidentally, also, the experimenters reported evidence that a bat's aural mechanism is capable of receiving such high-pitched sound. The full report of these experiments is intensely interesting and is strongly recommended for reading in full.

The experiments offer another very important illustration of the scientific method. Bats might be expected to differ in their abilities just as do pole vaulters and golfers. How is allowance to be made for such differences so that a true generalization may be drawn from the experiments? The answer to this question is covered by the description of the experimental arrangements which permitted quantitative results. The experiment was conducted in a room with padded surfaces, acoustically non-reflecting, which precluded confusion on the part either of the bats or of the experimenters themselves. A row of wires, suspended from the ceiling, constituted the obstacles. A count was made of the number of times the wires were hit by each bat in flying from one side of the room to the other.

There were wide variations among different bats, as one would expect. The least competent did little better than might be expected on the mere basis of probabilities for his size (wing span). A calculation for the probable number of times that wires would be struck in the passage across the room of an equal sized but volitionless object furnished the comparison. Each bat was put through his paces, that is, his flight, 50 times and individual records were kept. Combination of the records for all the bats—and the

[1] R. Galambos, Sci. Mo. **56**, 155 (1943).

number was sufficient for statistical purposes—gave a measure of bat ability. Knowing the natural ability there remained only to tamper with it, while keeping other things equal—as the experimenters did—and then to compare the new statistic with the norm. The results appear conclusive.

There are analogies of great practical interest to the bat's flight in the dark. In modern terminology bats may be said to "sound range by echoes." Sound ranging by acoustic echoes has been used for years in measuring the depth of ocean floors. It has also been applied, using the electromagnetic waves of radio, to the design by Bell Telephone Laboratories of an airplane altimeter. This can indicate to a pilot his height above the earth whereas the aneroid barometer, giving altitude above sea level, supplies no information as to the nearness of terrain immediately below the airplane. Methods of ranging by reflected waves of either type are, of course, capable of wide variation and application. One might, therefore, assume that they could be applied, and probably are, to military problems.

The Training of Weather Officers in Wartime

Carl B. Allendoerfer
War Department, Washington, District of Columbia

It is a sign of the times that I, a mathematician, am addressing a group of physicists about meteorology. It is a sign that in this country meteorology has come of age as a physical science. No longer can a weather man limit himself to a knowledge of cloud formations, weather maps and his own intuition. He must now be an atmospheric physicist and a radio technician as well. Advanced training in meteorology of graduate level is now available in five universities, and departments of meteorology are beginning to stand on their own feet.

The recent advance in meteorology is concerned chiefly with the physics of the upper air and with the development of new measuring instruments. Together these improve the quality of the local forecasts and also enable the weather man to make long range forecasts of climatic conditions. One of the more modern branches is *dynamic meteorology*, which is concerned with the hydrodynamics of the atmosphere under the influence of changing temperatures, pressure and humidity conditions, taking in to account the rotation of the earth. The full understanding of this material requires a thorough knowledge of calculus, classical mechanics, hydrodynamics and thermodynamics. The new observational technics involve the use of electric and radio equipment, with which the meteorologist must be familiar. A good course in these subjects is thus essential in the training of weather men.

The development of these new technics has been spurred forward by the well-known requirements of aviation, but did not gain its full momentum until the outbreak of the present war. The role played by the weather in military operations should be apparent to anyone. For instance, long range flights of all types must be planned to take advantage of adequate visibility at the objective, proper cloud cover over enemy territory, absence of icing conditions, and the strength and direction of the wind. Doubtless you will recall the unfortunate experience of the British in a raid on Berlin last year, when weather conditions caused a loss of some 30 bombers. There are numerous cases of this sort, similar in kind but not in extent, which have not reached the public press.

The Air Forces, however, are not the only ones dependent on the forecasts. Soil conditions which prevent the operation of mechanized equipment and storms which upset carefully planned operations can mean the failure of an important campaign. Perhaps the most celebrated strategic use

of weather in this war was the escape of the Gneisenau and Scharnhorst in the midst of the sort of conditions that normally suspend travel across the English Channel. The Japanese operations in the Aleutians and their attack on Pearl Harbor also made excellent use of cover afforded by clouds. The extent to which the United Nations are using the weather in their calculations cannot be disclosed, but we are not neglecting this matter by any means.

Previous to the entry of the United States into the war, advanced training in meteorology was being given in a number of far-sighted American universities. The course of study was at the graduate level leading to a master's degree, and required a strong undergraduate major in mathematics or physics. The number of graduates, however, was very small owing to the limited opportunities for the employment of meteorologists. The Army and Navy soon realized that the number of trained weather men in the country was woefully inadequate for their needs. The leading graduate schools which had this specialty were called upon for help in meeting the deficiency, and they responded magnificently. The University Meteorological Committee, consisting of representatives of Massachusetts Institute of Technology, the University of Chicago, New York University, the University of California at Los Angeles and California Institute of Technology, was established to coordinate the curricula of these institutions and to distribute the teaching load according to their capacities. As a result the Army and Navy have sent increasingly large classes of men to be trained in these schools.

It soon appeared that insufficient men were on hand to meet the previous entrance requirements of this course and, further, that the course was too long if weather officers were to be available when needed by the services. As a result men were admitted after two years of college provided they had studied elementary calculus and physics, and the advanced course was shortened to eight months. Soon after this the Army set up its own school at the Weather Training Center, Grand Rapids, Michigan, which is giving graduate training at the same level as the five universities.

After this plan had been in force for a short time, however, the available supply of men with even these reduced requirements was insufficient. To meet the need the Army Air Forces have undertaken to train men at government expense in pre-meteorology courses that will qualify them for the *A*, or advanced, course. Two courses with this objective are being established:

Course B. This is a six months' course designed for men who have had one year of college training including a year of college mathematics (algebra, trigonometry, analytic geometry). The curriculum will consist of mathematics (elementary calculus, differential equations, topics from advanced calculus), mechanics (classical mechanics, vector analysis, emphasis on relative motion), general college physics, physical geography, and elements of composition and speech.

Course C. Candidates for this course must have completed high school and have studied plane geometry and one and one-half years of algebra. The instruction will cover a year's time and will include the material presented by Course *B* plus the necessary preliminary work in mathematics and a course in American History.

As of March 1, the opening dates for the various courses were: *Course A*. January 4, March 29, June 21; *Course B*. March 15, May 15; *Course C*. February 15, May 15.

The following institutions are giving pre-meteorology training:

Amherst College
Bowdoin College
Brown University
Carleton College
Denison University
Hamilton College
Haverford College
Kenyon College
Massachusetts Institute of Technology
New York University
Pomona College
Reed College
State University of Iowa
University of California (Berkeley)
University of Chicago
University of Michigan
University of Minnesota
University of New Mexico
University of North Carolina
University of Oregon
University of Virginia
University of Washington (Seattle)
University of Wisconsin
Vanderbilt University
Washington University (St. Louis)

Admission to the *B*- and *C*-courses is now closed as a result of the large number of qualified applicants. Applications for admission to the *A*-course should be sent to "Weather," Chicago, Illinois. Full information concerning the training program may be obtained from the Assistant Chief of Air Staff for Training, War Department, Washington, D. C.

Student Contributions to the Physics Laboratory

F. Buckley
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SMALL-SCALE research, construction of new laboratory apparatus and demonstration models, and development of new experimental procedures are trying undertakings in a small college. The usual heavy burden of teaching leaves little time available for such projects. Even under the most favorable circumstances of adequate expenditure for equipment the instructor remains seriously hampered because of the necessity of adhering to procedures employing commercial equipment. The construction of new apparatus and models is often retarded because of a serious lack of capable assistants or interested students and the general unavailability of materials and facilities. The writer's experience has been that under optimum conditions for developmental work, few students display sufficient interest or curiosity to undertake singly or cooperatively the construction and testing of new equipment. When rare examples of initiative do appear there is a strong impulse to face the East and give thanks for miracles.

The apparatus and tests described in this article represent the achievements of a few of the more curious scientific neophytes.

MOMENT OF INERTIA

The general features of design of the apparatus shown in Fig. 1 were worked out in short student conferences. Division of labor and responsibility was determined by individual aptitudes. All machine work and assembling was done in the college shop. Patterns for the supporting castings were made by one of the students in a home woodworking shop. The castings were poured by the local foundry.

Difficulties already alluded to prevented further experimentation in design, and hence no claim can be made for optimum values. Many of the final decisions regarding size were made by the students. Details of construction are shown in Fig. 2. The disk is mounted on ball bearings.

Preliminary tests showed the apparatus to be capable of results well within 2 percent. Accordingly, two students from the engineering physics class were selected to make a series of trial runs. The theory of the experiment was reviewed, general difficulties of technic were pointed out, and the students were instructed to select their own final procedure after preliminary experimentation.

Method of procedure.—The procedure is extraordinarily simple compared with that employed with the usual commercial apparatus using a spark timer or equivalent. The determination of moment of inertia required the measurement of: (1) mass of the falling body, (2) dis-

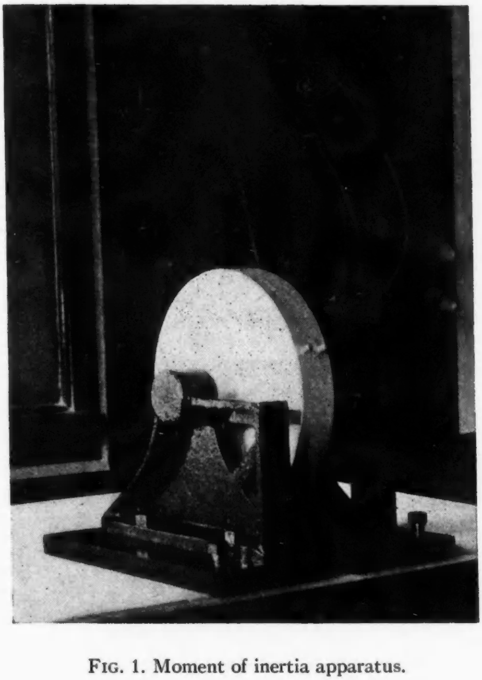

Fig. 1. Moment of inertia apparatus.

tance of fall and (3) angular velocity of the wheel at the time the weight was released. The first and second data are measured directly, and the last is obtained by graphical methods.

The required angular velocity ω was determined as follows. Successive groups of revolutions were timed by means of stop watches, and the average angular velocity for each interval was computed. Angular velocities were plotted against the midpoint of the time interval, and the intercepts of the curves on the angular velocity axis were taken as the required initial velocities. Frictional effects were assumed constant. Results of the tests are shown in Fig. 3.

Treatment of data.—A graph of the experimental data and a little argument concerning the lines of "best fit" soon convinced the students of the necessity of introducing some criterions for selecting curves most representative of the experimental data. This opportunity was taken to review the general problem of experimental error and to apply the theory of least squares to the linear case. The students were much interested and did not consider the extra computations a burden. The lines of Fig. 3 are drawn in accordance with their calculations.

The problem of correcting for frictional effects was also an intriguing one. After a lively discus-

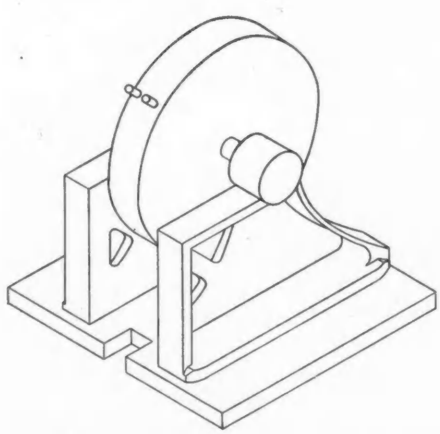

FIG. 2. Diagram of moment of inertia apparatus. Radius R of wheel, 12.8 cm; thickness of wheel, 4.1 cm; diameter of shaft, 2.07 cm; mass of disk and shaft, 16.66 kg.

sion in which numerous suggestions were advanced to correct for these effects it was decided to lump them all into a factor k in the potential energy term of the energy equation. The moment of inertia was then calculated from the equation,

$$kmgh = \tfrac{1}{2}mv^2 + \tfrac{1}{2}I\omega^2, \qquad (1)$$

which gives

$$I_{\text{exp}} = m(2kgh - R^2\omega^2)/\omega^2. \qquad (2)$$

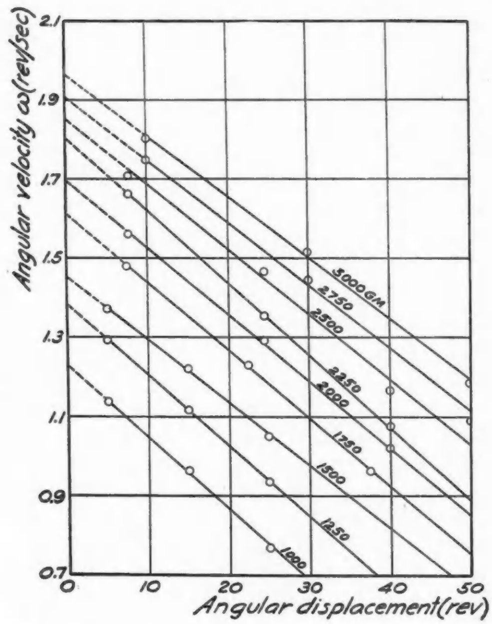

FIG. 3. Angular velocity *versus* angular displacement.

The value of the experimental constant k was determined by forcing a fit of the data for the trial in which m was equal to 1000 gm. This value of k was then used to calculate I_{exp} for the remaining trials from Eq. (2). A summary of the

TABLE I.

Weight (gm)	I_{exp} (10^6 gm cm^2)	$(\Delta I/I)\times 100$
1000	1.36	0
1250	1.37	0.73
1500	1.46	(7.8)
1750	1.33	1.7
2000	1.35	0.73
2250	1.30	(4.4)
2500	1.34	1.2
2750	1.37	0.73
3000	1.38	1.5

$I_{\text{cal}} = 1.36\times 10^6$ gm cm^2; $k = 0.947$; avg. dev. $= 0.93$.

results of the test is given in Table I. If the third and sixth trials are omitted, the average deviation from the mean is 0.93 percent. The results are on the whole satisfactory. The rugged construction of the machine and the particularly simple procedure which has been shown to be adequate makes the apparatus a valuable addition to the freshman physics laboratory.

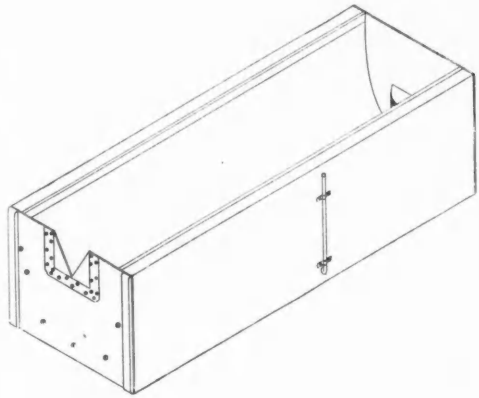

FIG. 4. Design of weir: length, 35.5 in.; trough radius, 11.5 in.; angle of notch, 60°; thickness of notch, $\frac{1}{16}$ in.

THE 60° WEIR

For the past several years the writer has introduced and developed the subject of fluid mechanics through its more practical applications in the field of hydraulics. In the discussion of the laws of fluid flow the Venturi meter and the weir are offered as important applications. The basic equations for the rate of delivery are developed, and a brief résumé of the various factors affecting the characteristic meter constants is given. The weir described here is the result of a suggestion that such a flow meter would be an interesting and valuable addition to the physics laboratory. It was designed and constructed by one of the sophomore students particularly interested in this topic. In fact, the writer was unaware that the student had undertaken the project until the weir was completed and delivered to the laboratory for test.

Construction details.—The general design with dimensions is shown in Fig. 4. The frame of the tank is made of mahogany, the trough and front plate of galvanized iron, and the weir notch and honeycomb baffle at the inlet of brass.

Procedure and results.—A steady state was indicated by a manometer (Fig. 5) inserted in the supply. Rate of delivery was determined directly by measuring the quantity of water delivered into a calibrated tank in a given interval of time.

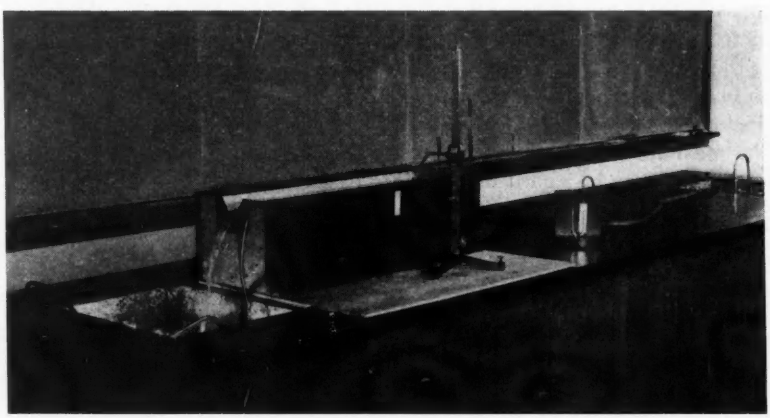

FIG. 5. The weir.

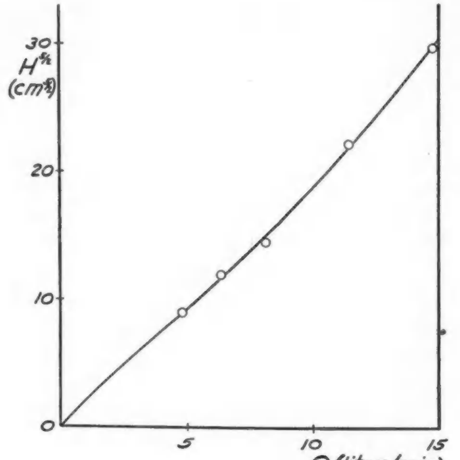

FIG. 6. $H^{5/2}$ *versus* rate of discharge. The slope is $1/K$.

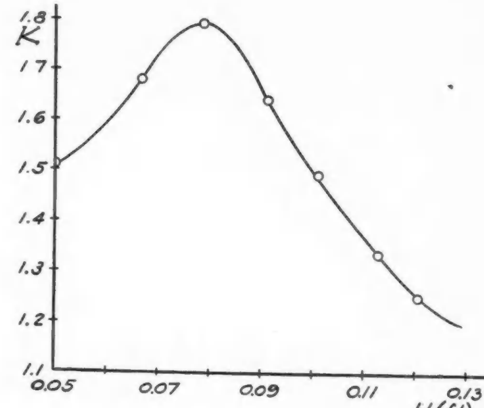

FIG. 7. Weir constant *versus* head.

The driving head was measured with a cathetometer equipped with a sharp-edged pointer. The averaged results of several trials at various heads are shown graphically in Fig. 6. It is observed that the ideal law, $Q=KH^{5/2}$, where Q is the discharge rate, is not exactly valid, but exhibits an inflection point in the neighborhood of $H^{5/2}=10$. To display the variation of the weir constant K with the head H more effectively, a graph of the slope of the calibration curve (Fig. 6) *versus* H was constructed (Fig. 7). This curve shows a distinct maximum for H equal approximately to 0.08 ft.

Considering the extreme sensitivity of K to the characteristics of the weir notch—for example, sharpness, thickness, turbulence, angle—particularly at the maximum, the values obtained for K as a function of H can be regarded as comparing favorably with those reported in the literature. The experiment of calibration has proved a valuable extension to the repertory of the elementary physics course.

MOLECULAR AND CRYSTAL MODELS

The great need for models is evident to any instructor who has attempted to convey the essential spatial ideas of molecular and crystal structures to beginners. Solid and transparent models of representative types of ideal crystals belonging to the various crystal systems and certain important lattice structures have been (before the War) available commercially. Nevertheless, in spite of the need for reasonably cheap and well-constructed models, there is no general source of molecular models, close-packed structures or Bravais lattices. The task of constructing sufficient models is not one of great difficulty for a large institution where several departments can cooperate, and where both facilities and skilled

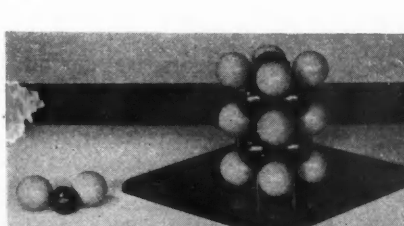

FIG. 8. Molecular and crystal models.

labor are available. In the small school any such construction program can be realized only piecemeal and over a long period of time. Such a program was initiated several months ago at the Canal Zone Junior College but has since been abandoned because of lack of materials. The models shown in Fig. 8 were constructed of substitute materials and have already served a useful function in teaching the rudiments of crystal structure.

The customary spheres of wood, plastic, rubber, and so forth, used in such model work were replaced by the only substitute available on the entire isthmus, namely, cork fish floats. These floats are reasonably spherical in shape, but have the disadvantage of possessing a very rough surface and hence are difficult to paint. However, a sufficiently smooth surface can be prepared by using putty as a filler and thick lacquer for a glossy finish. In the close-packed hexagonal and face-centered cubic structures alternate layers are painted bright red and green. The effect is very striking. The stringers in these models are glass rods which, though very fragile, have proved satisfactory as substitutes for brass tubes or rods. The lattice structures are mounted on varnished mahogany bases.

In the molecular models the spheres are bound to each other by connecting wooden pegs and glue. They give light durable structures. Hydrogen is painted white, chlorine green, oxygen red and nitrogen blue.

It is impossible adequately to exhibit relative molecular or ionic sizes in the molecular models because of the limited choice of spheres. In the molecules shown in Fig. 8 for H_2O, Cl_2O and NH_3, the finished spheres had diameters of 2.60, 3.92 and 5.18 cm, giving the ratios: $O/H=1.50$; $N/H=1.99$; $Cl/O=1.32$. These ratios compare favorably with the corresponding ratios of covalent radii given by Pauling; namely, 1.90, 1.83 and 1.73.

* * *

The laboratory is especially indebted to the following students: Messrs. C. Daniels, P. Welch, J. Schnake, D. Myers and K. Campbell. Detailed drawings of the apparatus were provided by students of Mr. Zierton's.

An Important Notice Concerning Pre-Induction College Physics

EVERY physics department offering the pre-induction course in college physics should vigorously oppose any local attempts to relegate the course to the sophomore year. Of all the pre-induction courses, physics is the most important, and it must be given in the freshman year if the largest number of students is to be reached. The argument that the first-year students will lack certain prerequisites is not valid; in the physics course outlined by the War Department and U. S. Office of Education, the only prerequisites are high school algebra and geometry. A course in college mathematics is not required; the physics course itself begins with a survey and review of the mathematics needed for the course. Official opinion on this matter is reflected by a statement sent in April to all physics departments by the Chief of the Division of Higher Education, U. S. Office of Education:

> Owing to the great need of the armed forces and of industry for men and women who understand the principles of physics, and to the fact that in the near future many men and some women will likely be in colleges for one year only, it is believed that instruction in physics should be given to freshmen; it should not be delayed until the sophomore year.

The War Department and U. S. Office of Education have sent two mimeographed copies of Parts I and II, combined, and Part III of a *Teachers Guide for Pre-Induction College Physics* to the *head* of every university, college and normal school physics department in the country. All interested physics staff members should be given an opportunity to study this guide and to offer suggestions for its improvement. These suggestions may be sent at any time to the U. S. Office of Education.

Part I describes Army needs and occupations for which physics instruction is foundational, suggests possible changes in college physics in the light of these needs, and specifies the type of student and the institutional level for which the suggested instruction is appropriate. Parts II and III are somewhat detailed outlines for mathematics, mechanics, heat and electricity, prepared by K. F. HERZFELD, K. LARK-HOROVITZ, E. P. MILLER and G. D. ROCK. Part IV, on wave motion, sound, light and radio, is in preparation.—D. R.

NOTES AND DISCUSSION

Phonograph Recordings of Talks by Physicists

JOHN HARTY
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PHONOGRAPH recordings of short, informal talks by American physicists who have distinguished themselves by far-reaching discoveries should prove to be very stimulating to students. Sound motion pictures would of course be better, since apparatus could then be shown as the man is lecturing. It is suggested that the American Association of Physics Teachers consider the possibilities of arranging for suitable speakers and for having the proposed material recorded and distributed. Perhaps some readers of this note can make additional suggestions concerning the proposal.

Starting an Automobile on a Slippery Road

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IN a recent college textbook[1] which is notable for its thought-provoking discussions of familiar things we find the following remarks:

> An automobile is started and kept in motion by the forward thrust of the ground on the rear wheels as these wheels are turned by the engine. As long as the tires do not slip on the road, the effective force is the force due to static friction; and since static friction is greater than sliding friction, a wise driver tries to avoid spinning his wheels. On icy streets, even static friction is small. Any attempt to accelerate the car rapidly calls for a force ($F=ma$) greater than the possible frictional force between tire and ice. To make the car's acceleration as small as possible, the wheels should be turned slowly; and this is best accomplished by starting in low gear and with the lowest engine speed that does not cause the engine to stall.
>
> There is an idea more or less prevalent that a driver should start in high gear on slippery streets. If such a practice fails to spin the wheels, it is either because conditions are right for a lucky start or because the engine when in high gear is unable to turn the wheels at all and accordingly stalls.

The reasoning is sound; yet the conclusion that low gear should be used seems to be at variance with the opinions of many competent drivers. A canvass of some twenty of the writer's colleagues, who are physicists or engineers, and drivers of long experience, indicates that there are circumstances in which a successful start may be made in high gear after futile attempts in low and second. Indeed, most of these men feel sure that the high-gear start up a moderate grade on an icy road is always the best. A few, however, are just as sure that low gear is always the best. Is it not possible that both groups fall into the common error of over-simplification?

Among the conditions that must be satisfied before a car can start up a slippery incline are the following:

1. The tangent of the angle of inclination must be less than the static coefficient of friction.

2. The average torque applied to the rear axle must be larger than that which will hold the car in equilibrium on the incline, but smaller than that which will spin the wheels.

3. The driver must be skilful enough, and the clutch smooth enough, to meet Condition *2*.

Conditions *1* and *2* need no discussion. Condition *3* implies that the poorer the clutch is, the better the driver must be. A mechanical engineer informs me that a "soft" clutch is easily handled but requires frequent adjustment; a "hard" clutch tends to grab and chatter but wears well; the good designer compromises between these extremes. I have not been able to find a curve showing the torque transmitted by a slipping clutch as a function of pedal position, engine speed being constant. I suspect that such a curve would be discontinuous near the origin, showing that at a given engine speed a slipping clutch will not transmit any torque less than a certain minimum. This is consistent with the "stick-slip" theory of solid friction.[2] With a fluid clutch, or with a conventional clutch good enough to transmit torque less than that which will spin the wheels in low gear, the choice of low gear is admittedly correct. Otherwise, either second or high may be necessary. It will be recalled that the conventional transmission multiplies any torque delivered to it by the clutch; the multiplying factor is about 4, 8 or 16, depending upon whether high, second or low gear is used. This is true whether the clutch is fully engaged or not. Thus, a driver who cannot avoid spinning the wheels in low gear may halve the minimum torque transmitted to the rear axle by shifting to second. If this torque satisfies Condition *2*, he will start the car. If not, he may halve the minimum torque again by shifting to high. It is presupposed that the driver is not so unskilful, nor the clutch so harsh, as to stall the engine.

By way of corroboration we note the behavior of a well-known make of car with a fluid transmission, as reported by a local user. If the wheels spin on a slippery pavement, the transmission promptly shifts automatically to a *higher* gear, the wheels cease to spin and the car moves forward as it should!

We now re-examine the quotation to see exactly where the divergence of opinion arises. It is in this sentence: "To make the car's acceleration as small as possible, the wheels should be turned slowly; and this is best accomplished by starting in low gear and with the lowest speed that does not cause the engine to stall." The first statement is unimpeachably correct. The second seems to imply that a car cannot move as slowly in second or high as it can in

low. This is true only if the clutch is fully engaged, which is not the case when the car is starting. Low gear is the best choice if the clutch is so good that a very small torque can be smoothly delivered, or if it is so bad that it grabs and stalls the engine in any gear but low! Usually its condition is somewhere between these extremes. Then, no matter how skilled the driver, a low-gear start may be impossible; but a start in a higher gear may be, and often is, perfectly feasible.

[1] Harley Howe, *Introduction to physics* (McGraw-Hill, 1942), p. 125.
[2] Morgan, Muskat and Reed, J. App. Phys. **12**, 743 (1941); Bowden, Moore and Tabor, J. App. Phys. **14**, 83 (1943).

Should Joule's Law or Ohm's Be Regarded as Basic?

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IN the cgs system there are two ways of defining the electromagnetic units. The sequence is either m, H, I, Q, E, R, and so forth, or m, H, I, Q, R, E, and so forth. The difference is in the choice of Ohm's law or Joule's law as a basic principle. If Ohm's law is chosen, E is defined as W/Q, and then R is obtained from the relation $R=E/I$. Joule's law follows, and is usually treated as an independent experimental generalization, although it may be derived by combining the equations $E=W/It$ and $E=IR$. On the other hand, if Joule's law is chosen as basic, then R is defined from the equation $W=I^2Rt$, and E follows from the Joule equation, transformed to read $W/Q=IR=E$. Ohm's law is then obtained from this definition of E.

The method based on Ohm's law is much more usual than the one based on Joule's law. An examination of 23 textbooks of general physics including one in German and one in French revealed that 19 prefer Ohm to Joule, and only four put Joule first. The authors of these four are Reed and Guthe, W. S. Franklin, Ferry, and Lemoine and Blanc. As both methods are logical, one concludes either that the more usual form is more easily grasped by beginners, or that Ohm's law still holds a place of pre-eminence which seems to me exaggerated.

Although I have yielded somewhat reluctantly to the popular verdict in a forthcoming revision of my shorter textbook, I wish to take up the cudgels in favor of the less usual method of defining E and R. In the first place, Ohm's law is less general than Joule's, since it applies only to steady currents. To be sure, one may call the equation $I=E/Z$, where Z is the impedance, the "Ohm's law for alternating currents," but certainly an expression that depends upon the frequency was never contemplated by Ohm. In the second place, it is not very sound to define E before R has been introduced. The authors who approach it immediately after defining Q say that E, or ΔV, is measured by the work done per unit charge in carrying a charge from one point to another in an electric circuit. This statement is made either with no explanation of why work has to be done, or by introducing the notion of resistance before it has been defined. Obviously work cannot be done without some opposition, so the definition either is unconvincing or is actually illegitimate in that R is postulated to define E, and then is defined from the result by way of Ohm's law.

The alternate method has several advantages. Joule's law is always true for both alternating and direct currents. It is the vital connecting link between mechanical and electrical energy, and, though it followed Ohm's law historically, is really more fundamental. In giving it priority we obtain a definition of E without having to evade the question of the meaning of W. Ohm's law thus becomes a direct consequence of Joule's, which seems to be a sounder procedure than to obtain the more general Joule's law from the more limited Ohm's law. In either case only one of the two laws need be regarded as the result of a fundamental experiment, so there is no choice from that angle. However, the preference for Joule over Ohm seems to have enough advantages to warrant demoting Ohm's law from the almost sacrosanct pre-eminence it has long held to an honorable but secondary position in the theory of electromagnetism.

Mechanical Drawing in Teaching Mechanics

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TWO difficulties which beginners experience in understanding elementary mechanics problems may be removed by employing principles derived from mechanical drawing.

The first application is an extension of the concept of *scale*. Consider the problem of finding the force in the tie-rope of a crane (Fig. 1). The student readily understands the construction of a scale drawing, in which the scale is, say, 1 in. = 1 ft. The next step, that of relating the forces

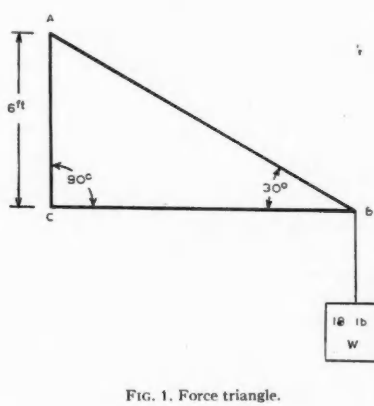

FIG. 1. Force triangle.

TABLE I.

Line	Length of line in problem (ft)	Force along or parallel to line in problem (lb)	Scale Force/length (lb/ft)
AC	6	18	3
AB	12	36	3

to the corresponding elements of the figure, is more difficult for the beginner. To each length, or parallel to it, there is a corresponding force. To relate the weight W to the length AC directly on the figure only complicates the process unnecessarily. It has been found convenient to make a table (Table I) showing the "scale," that is, the relationship of "pounds of the problem" to "feet of the problem." Once the student understands that each force is along the line or parallel to it, the "scale" is understood, and it is the same for all lines in Fig. 1.

A second principle of drawing that may be effectively utilized in clarifying elementary mechanics problems is that of correctly indicating the dimensions of a drawing. The following problem will illustrate. A horizontal bridge 50 ft long weighs 100 tons. The center of gravity of a 60-ton locomotive is 20 ft from one end of the bridge. Find the forces on the two abutments. This is a simple torque problem in which all forces are vertical and all lever arms are horizontal.

An adequate diagram requires mainly that each dimension shall indicate precisely between which two points it applies. Figure 2 is an example of a diagram having poor

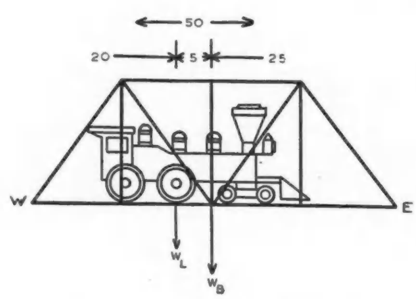

FIG. 2. Example of poor dimensioning.

dimensioning; the 50-ft arrowheads do not show that they refer to the length of the bridge, and the arrowheads between 20 ft and 5 ft are poorly placed. It is easy to mark an × and have it serve as a pair of arrowheads, but this often causes confusion. A further fault of Fig. 2 is the omission of the units of measurement.

A better diagram is shown in Fig. 3. The arrowheads are independent. The dimension lines are not collinear, and all come from one common reference point—in this case, W. The method of indicating dimensions from one end of the

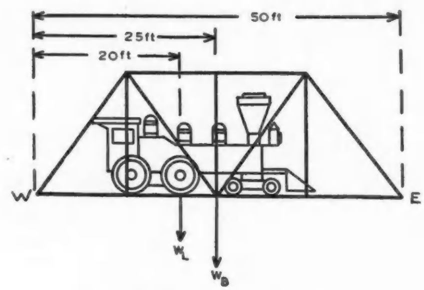

FIG. 3. Preferred dimensioning.

diagram, or at least from one point, is common practice in mechanical drawing, to avoid "pile-ups" of tolerances; its use in physics simplifies the concept of the lever arm.

Charts as Teaching Aids

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NOW that world conditions have brought physics into its true focus, more attention than ever must be given to teaching methods. In the rush to cover physical principles most needed by warring nations, the over-all view of physics as a science may be neglected. Certain teaching aids which have long been available but possibly not given just consideration may suddenly come into popular use and partially remedy this deficiency by correlating separate data into a unified whole. Among these aids are charts, to which this note will be mainly confined.

Besides the well-known "Periodic chart of atoms," by H. D. Hubbard and W. F. Meggers,[1] and "Chart of the metals,"[2] there is available a "Chart of electromagnetic radiations," by A. H. Compton,[3] which compactly portrays the fundamentals of this important branch of physics. Leading logically from simple laws this outline carries one progressively through the production of electricity to the nucleus of the uranium atom and recent studies of cosmic rays. Over 150 diagrams with explanatory notes are artistically combined with both wave and frequency scales of the entire radiation spectrum to provide the student with as comprehensive a picture as it may be possible to gain from a single chart.

Fortunately, radiation charts are available in student sizes. The periodical, *Electronics*,[4] for example, offers the fundamental data on a 10×14-in. sheet portraying the full electromagnetic spectrum in colors. The "Frequency spectrum of the electronic industries," supplied by the publication, *Electronic Industries*,[5] is a somewhat more ambitious treatment of the same material which has recently been prepared by specialists of the General Electric Company. Besides tables of reference constants and basic formulas, frequency segments of the well-reproduced spectrum corre-

spond with thumbnail illustrations of representative electronic equipment. A seven-color wall chart prepared by the Westinghouse Research Laboratories[6] follows a similar pattern.

M. L. Pool portrays the rapid developments in the fields of the electron and nucleus in his "Nuclear transmutation chart."[7] Recent advances have made it desirable to record conveniently the stable, naturally radioactive and artificially radioactive nuclei of the elements, the formation of their isotopes and the behavior of certain members under bombardment from protons, deuterons and neutrons; and this Doctor Pool has effectively done.

Taking their obvious place in the scheme of lecture room and laboratory, these charts assume greater utility when either projected as lantern slides or placed in the hands of the students in manageable sizes. While the afore-mentioned charts are not available commercially as slides, they are readily reproducible in this form by color photography. As many as six to a dozen slides may profitably be used in presenting charts, first in their entirety and then in appropriate components. In the case of the Hubbard-Megger chart, slides of the individual rectangles which contain some 30 different characteristics of a given atom are often useful. There are instances where a printed card for each element and its related information would be helpful.

The Central Scientific Company has long pioneered in the instructional aspect of physics, beginning in 1925 with its *Cumulative Unit Experiments in Physics* and expanding, with the aid of five prominent teachers—V. E. Eaton, M. J. Martin, R. S. Minor, M. W. White and R. J. Stephenson—to the well-known *Selective Experiments in Physics*. In 1939 this company published the highly commendable lecture outlines and record sheets by W. S. Webb and B. P. Ramsay of the University of Kentucky's course, "Introduction to physics," which incorporates two useful charts adapted to notebook, lecture-room projection and decorative wall purposes. The first lecture of these *Demonstration Lectures in Physics*, called "Physics as a science," incorporates a student-size "Map of Physics"[8] that traces the historical development of the six major branches of physics from early Greek times to the present by means of an interrelated river system having the names of principal contributors listed along its banks. Numerous symbols, diagrams, definitions and lists of important discoveries and prize-winning physicists are also included to provide the student with a compact panorama of the field of physics. Color slides of the map, although not available commercially, have been used successfully in the opening lectures of the first-year course at Brown University, while wall sizes[9] contribute to the teaching and decoration of other institutional classrooms and libraries.

The second lecture of the Webb-Ramsay series employs a reproduction of the John Norton mural, "Tree of knowledge—basic and applied sciences," which depicts forcibly the interrelation of all sciences. Copies are also available in larger sizes.[10] Useful facsimiles of his mural "Dimensions of natural objects,"[11] not included in the lectures, show the comparative dimensions of natural objects ranging from galaxies to protons.

No more than mention need be made here of the standard charts on atomic weights, periodic arrangement of the elements, measuring systems, weather forecasts, and so forth, whose utility has long been recognized. The suggestion that they be lowered from their normally high perch, dusted off and brought into revitalized use might not be amiss, however.

[1] Welch Scientific Company, 42×58 in., $5.
[2] Reference 1, 25×42 in., $2.75.
[3] Reference 1, 42×64 in., $10.
[4] McGraw-Hill, 25 cts.
[5] Caldwell-Clements, Inc., $1.
[6] Publications Section, 6-N-17, 30×40 in., $2.
[7] Reference 1, 42×50 in., $5.
[8] By B. H. Porter, 8.5×11 in., $3 for 100 copies.
[9] 35×45 in., $2.
[10] Central Scientific Company, 28×45 in., 75 cts.
[11] Museum of Science and Industry, Chicago, 25×36 in., 30 cts.

Misconceptions About Science

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PROFESSOR Perkins' stimulating list of misconceptions about physics could be paralleled by a list of misconceptions about science in general. *Many people without special training in scientific subjects think:*

That scientific researchers nearly always work in pursuit of some desirable practical end. It is supposed, for example, that the immediate object of medical research is uniformly to find cures for diseases.

That so-called scientific honesty is a moral virtue. Only on closer inspection does one see that it is an indispensable trade technic.

That a measurement is not scientific unless it is accurate. It is not widely known that no good physicist would claim that he ever got even one measurement really right. It would surprise many to be told that a determination of the dimensions of a galaxy or of an electron might easily miss the mark by 100 percent and still be valuable and "scientific."

That peculiar or picturesque scientists are the best ones.

That the scientific vocation is one of constant association with amazing facts, houses of magic and believe-it-or-nots. The dominant role of hard work and straight thinking in this calling has not been greatly publicized.

That science, or important branches of it, get "revolutionized" at frequent intervals, the books and theories of one decade setting at naught the ideas of preceding years. The improbability that by-products which really work could have sprung from a science that did not know which way it was going from one decade to the next is frequently overlooked.

That the way to make a scientific discovery of great benefit to the human race is to try to make a scientific discovery of great benefit to the human race.

Most of these misconceptions can be traced to the way in which science has been handled by newspapers and popular magazines. The reporting of science has come a

long way in the right direction in the last 20 years, but it has not come far enough to correct errors such as those listed here, since in many cases the reporters themselves entertain these misconceptions.

Common Misconceptions Among First-Year Students

IN the preceding issue we supplemented Professor Perkins' interesting list of misconceptions[1] with a brief one of our own making,[2] restricted to misconceptions and misinformation of a physical character that are often possessed by those who have not studied physics. We suggest now a list that is applicable to students who have had as much as a year of elementary work. This list, like the earlier one, contains many familiar items, some of which have been discussed by other authors in the pages of this journal. Nevertheless, they may bear reiteration, particularly at a time when many departments find it necessary to utilize teachers of relatively little training and experience in physics.

Some students leave the elementary course with the impression:

That Galileo invented the experimental method.

That a cubic centimeter of water weighs 1 gwt and, conversely, that 1 cm^3 is the volume occupied by a quantity of water that weighs 1 gwt.

This statement would not be correct even if the kilogram had been accurately constructed in accordance with its original definition, for 1000 cm^3 of water would have weighed 1 kgwt only if at 4°C and in vacuum, conditions under which the weighing of water is impracticable. Incidentally, the ambiguous abbreviation "cc" should be discarded; it reads "cubic centimeter" but more often is used when the milliliter is intended.

That 1 cm/sec/sec = 1 cm/sec^2, uniquely.

That a negative acceleration always corresponds to a diminution of velocity.

That the *pound weight* and other gravitational units of force, as they are defined in physics, vary in magnitude with the locality.

That inertia is the "cause" of mass, or vice versa.

That Galileo's principle of inertia—Newton's first law—is subject to *direct* experimental test; more generally, that an axiom (or principle) can be proved by direct experiment.

That Newton's second law of motion provides the best definition of mass as well as of force.

That neither axioms nor unconscious hypotheses are used, even implicitly, in elementary physics.

That, using the earth as the frame of reference, one may say, "when a man jumps upward off the earth, the earth undergoes a downward acceleration."

Similarly, one might say that a man can outrun himself and thereby arrive at his destination before he gets there.

That statics is confined to the study of bodies that are at rest.

That a body in mechanical equilibrium is necessarily at rest.

That the physical concept of *work* lacks general applicability, as is illustrated by the fact that a person becomes fatigued when he supports a heavy object without apparently moving it.

That a liquid surface behaves as if it were a stretched elastic membrane.

That the equations of Boyle and Gay-Lussac are simultaneous equations and may be thus combined to obtain the general equation of state for an ideal gas.

That a gas cannot have more than two specific heats.

That the passage of sound through a homogeneous gas is an adiabatic process because the frequency of sound is too high for heat conduction to be effective.

See E. U. Condon, Am. J. Phys. (Am. Phys. T.) **1**, 18 (1933).

That, if any given magnet is immersed in a medium of permeability μ, the magnetic field around it is similar to that in a vacuum, but diminished in strength in the ratio $1/\mu$.

That the production of a charge on one insulator when it is rubbed with another is due to friction; in other words, that the energy needed to separate the charges can be accounted for in terms of the work done against friction.

That the field intensity, or force per unit charge, at a point in an electrostatic field is necessarily equal numerically to the electrostatic force that would be exerted on a body bearing unit charge if it were placed at that point.

Similar considerations of course apply to a magnetic field and, to a less important extent, to a gravitational field.

That the ohm per cubic centimeter is a unit of resistivity.

That radiation, like conduction and convection, is a mode of heat transfer.

That the optical term *ray of light* refers to an infinitely narrow beam of light.

That diffuse reflection is an example of optical dispersion.

That the candlepower of a light source is simply the power of the source.

Since the word "candlepower" is merely a substitute, and a poor one, for the term *luminous intensity,* it means neither radiant nor luminous power, but luminous power (luminous flux) per unit solid angle in a specified direction.

That only phenomena for which the principle of superposition holds are amenable to scientific treatment.

That extrapolation and interpolation are always equally valid processes.

That the number of figures that are significant can be increased simply by manipulating the data mathematically.

That dimensions are assigned to physical quantities, and not merely to their units; moreover, that these dimensions afford information about the "true nature" of the quantities.

See, for example, R. T. Birge, Am. J. Phys. (Am. Phys. T.) **3**, 102 (1935).

That there is only one "true" explanation of any particular phenomenon; more generally, that the choice of the

fundamental concepts, principles and definitions upon which a theory is based, and of the particular logical order in which a theory is developed, is necessarily unique.

Yet the idea that the choice is not unique—as one example, that it is possible to choose deductions from certain postulates as the fundamental assumptions and so derive the original postulates—is of great pedagogic value, since depth of understanding of a subject increases with the number of points of view from which it is examined.

That physical experiments and theories were initially worked out in the simple and elegant forms described in textbooks.

That laboratory work is necessarily less efficient than book study as an educative process.

* * *

Readers are urged to submit additional items, so that the final list will be as useful and comprehensive as possible.—D. R.

[1] Am. J. Phys. 11, 101 (1943).
[2] Am. J. Phys. 11, 110 (1943).

Common Errors

It is believed by many persons—

That glass can be cut under water with ordinary scissors.

That steel attracts lightning (but copper and even iron do not).

That mirrors attract lightning (commonly believed in Devon, where the remedy is to cover the mirror with a cloth).

That the moon affects the weather; for example, when the moon is in such a position as to "hold water" it will not rain.

That cats can see in the dark.

That an explosion would result if a lighted match were dropped into a gasometer.

That the pressure in a water pipe may be reduced by partly closing the entrance valve.

That "it isn't freezing that bursts the pipes, but thawing them out afterwards."—G. C. Bachelor, *Sch. Sci. Rev.* 24, 168–171 (1943). J. D. E.

Other Misconceptions

MASS and weight are the same thing.

In Newton's third law the action and reaction act on the same body.

A heavy object will roll down an incline more rapidly than a light object, the objects being similar in shape and homogenous, and friction being neglected.

A hollow body and a solid body of the same external size and shape will fall at the same rate in air.

The force of friction between two solid surfaces depends on the area of the surfaces.

The hydrostatic force on the base of a vessel due to the liquid it contains always equals the total weight of the liquid.

For a liquid flowing through a tube the pressure is increased where there is a constriction in the tube.

The weight on an object increases as its distance below the surface of the earth increases.

Larger tides on the earth are produced by the moon than by the sun because the gravitational force at the earth due to the moon is greater than that due to the sun.

The pressure in a large soap bubble exceeds that in a small one.

The velocity of sound in air varies with atmospheric pressure, the temperature being constant.

Hot water freezes more rapidly than cold water.

The specific heat of ice is 1 cal/g °C.

The position of a virtual image cannot be determined experimentally.

The main reason for making larger telescopes is to increase the magnifying power.

The same color is produced by combining beams of light of given colors or paints of the same colors.

Capacitances are computed in the same way as resistances for parallel and series circuits.

The kilowatt is a unit of energy.

Magnetic poles can be isolated.

As measuring instruments are improved, it will be possible to determine simultaneously both the position and velocity of an electron to any degree of accuracy desired.—Paul C. Fine

A LITTLE chemistry, physics or physiology has no value at all in ordinary life. I have never once found . . . where such scientific knowledge as I possess . . . has brought me the slightest advantage. . . . When our cars break down, we take them to a garage; when our stomach is out of order we go to a doctor. We live either by rule of thumb or on other people's professional knowledge.—G. H. Hardy, *A Mathematician's Apology.*

RECENT PUBLICATIONS

ASTROPHYSICS

Atoms, stars and nebulae. LEO GOLDBERG and LAWRENCE H. ALLER. 327 p., 150 fig., 14.5×21.5 cm. *Blakiston*, $2.50. This is the most recent volume of *The Harvard Books on Astronomy*, a series written and edited by members of the Harvard College Observatory Staff to provide beginning students and amateur astronomers with a comprehensive survey of modern astronomy. The present monograph, with its emphasis on astrophysical topics, should interest many physics students. It opens with a brief outline of some pertinent principles of atomic physics and physical optics, and passes to a discussion of the physical processes at work in hot and cold stars, pulsating and exploding stars, and the nebulous clouds of interstellar space. Four previously issued volumes of this series were described in an earlier issue [Am. J. Phys. **10**, 271 (1942)].

BIOPHYSICS

An introduction to biophysics. OTTO STUHLMAN, JR., Professor of Physics, University of North Carolina. 382 p., illustrated, 15×23.5 cm. *Wiley*, $4. The author has planned this textbook primarily for students of the biological sciences who have had a year's work in college mathematics, physics and chemistry and who wish to obtain a fuller appreciation and understanding of the applications of physics to biological problems. By *biophysical phenomena* the author means all biological observations that are explainable in terms of physical principles. Biophysically active x-rays and applied radioactivity are treated in the opening chapters. There follow chapters on visual and auditory biophysics. Applications of physical optics come next, in a chapter on the emission and absorption of biophysically active radiation, particularly the ultraviolet. A chapter is then introduced to illustrate how the study of molecular-film structures is revealing the nature of the living cell membrane. The problem of nerve conduction is next discussed. Finally, there is a chapter on compound and electron microscopes. Each chapter contains a list of problems and numerous references both to physical and to biological literature.

ENGINEERING AND APPLIED PHYSICS

Empirical equations and nomography. DALE S. DAVIS, Mathematician, Michigan Alkali Company. 209 p., 70 fig., 38 tables, 15.5×23 cm. *McGraw-Hill*, $2.50. The first half of this engineering textbook provides a detailed treatment of empirical equations, including the fundamental rectification methods found to be most useful to the engineer, and various methods of two-variable and three-variable correlation. The last half of the book is concerned with the theory and construction of alinement and line coordinate charts. The methods are illustrated by many excellent examples and problems for student solution drawn from recent engineering literature and actual industrial data.

X-rays in research and industry. H. HIRST, Assistant Director of Metallurgical Research, University of Melbourne. 127 p., 82 fig., 12×19 cm. *Chemical Publishing Co.*, $2.50. The purpose of this little book is to indicate types of industrial and research problems—particularly in physical metallurgy—to which x-ray methods may profitably be applied, and to outline actual x-ray practices and calculations. First there is some simple background material on x-rays and crystal structure. Then the various applications are described—investigation of alloy systems, identification of new phases, measurement of thermal expansion, estimation of grain size, applications to manufacturing problems, and so forth. The type used for the book is somewhat too small for reader comfort.

Electrochemistry and electrochemical analysis. Vol. III. HENRY J. SAND, Lately Head of the Department of Inorganic and Physical Chemistry and Lecturer on Electrolytic Analysis, Sir John Cass Technical Institute, London. 127 p., illustrated, 12×19 cm. *Chemical Publishing Co.*, $2.25. The main topics treated in this little volume, the last of a series of three on electrochemistry, are: (i) potentiometric analysis, (ii) conductimetric analysis and the dielectric constant in chemical analysis, (iii) determination of moisture by the measurement of capacitance and (iv) potentiometric determination of *p*H. The three books in the series are intended both for student use and to give analysts a comprehensive survey of electrochemical methods and principles, so as to enable them to choose such tests as may be applicable to their special problems.

Alternating-current machines. Second edition. A. F. PUCHSTEIN, Consulting Engineer, Celanese Corporation of America, AND T. C. LLOYD, Chief Engineer, Robbins & Myers, Inc. 665 p., 356 fig., 15×24 cm. *Wiley*, $5.50. Designed to provide a thorough course, with problems and many bibliographic references, this textbook for students of electrical engineering has now been revised so as to take into account advances made since the appearance of the first edition, in 1936. Thus the sections on alternators and synchronous motors have been rewritten to include the new methods of calculating alternator regulation and the concepts of direct- and quadrature-axis synchronous reactance. Current practices concerning standardized ratings, machine dimensions and characteristics are emphasized, thus serving to show that in building machines, these attributes are not chosen at random but must adhere to rather rigid standards. The main divisions of the book are concerned with synchronous generators, transformers, polyphase and single-phase induction motors, synchronous motors, alternators in parallel, synchronous converters, mercury-vapor rectifiers, series and repulsion motors. Only steady-state phenomena are covered, with the exception of an analysis of hunting under various conditions of synchronous-motor operation.

An introduction to fluid mechanics. Second edition. ALEX. H. JAMESON, Emeritus Professor of Civil Engineering, University of London. 255 p., 115 fig., 8 tables,

14×22 cm. *Longmans, Green*, $3.40. The University of London requires an elementary knowledge of fluid mechanics of all candidates in the Part I, B.Sc. (Engineering) Examination, and the present book was prepared originally as a textbook for such students. The author reminds us that no single, unified mechanics of fluids existed until some 35 years ago. Hydrostatics was in a satisfactory state, but motion in fluids was dealt with in two quite different subjects: *hydrodynamics*, which was strictly mathematical but confined to ideal fluids except for a few simple cases of viscous flow; and *hydraulics*, which was almost purely experimental and involved a bewildering mass of empirical formulas and tables of coefficients. The great advance in recent years has been due mainly to the rapid development of aeronautics and to the recognition that the *Reynolds number*, first used in 1883, constituted a criterion of the similarity of motion of all fluids. RAYLEIGH, following REYNOLDS, developed the method of dimensions, which has provided the generalization previously lacking in hydraulics. Experimental work on models in tanks had been developed by FROUDE for ship design, and the Reynolds number provided the key for corresponding aerodynamic work in wind tunnels. Today, experiments with scaled models are employed throughout hydraulics, even for such large-scale problems as those of erosion and of wave action on walls. Other factors have contributed to the growth of the science—for example, the development of turbines and of fluid fuels—until now we find rational formulas prevailing. The present book, in reflecting these trends, is relatively free of empirical formulas and tables of coefficients. Also characteristic of the book is the large number of worked examples. The second edition differs from the first (1937) mainly in that it contains new material on flow in pipes, in notches and over weirs.

GENERAL PHYSICS

Sub-atomic physics. HERBERT DINGLE, Professor of Natural Philosophy, Imperial College of Science and Technology, London. 272 p., 147 fig., 13×19 cm. *Ronald Press Co.*, $2.25. The second of a two-volume set of textbooks on physics for aeronautical students, this book covers the structure of the atom, optics, electricity and magnetism. A description of the general plan of the books and of the first volume, on *Mechanical Physics*, will be found in an earlier issue [Am. J. Phys. **11**, 49 (1943)].

College physics. Revised edition. HENRY A. PERKINS, Professor of Physics, Emeritus, Trinity College. 813 p., 595 fig., 15.5×23.5 cm. *Prentice-Hall*, $4.50. Having appeared first in 1938 [Am. J. Phys. **7**, 75 (1939)], this textbook has now been revised to include recent advances—for example, the fluorescent lamp, the electron microscope, the mesotron and nuclear fission—and to take advantage of many suggestions contributed by those who have used the book. The factor k has been eliminated from equations involving Newton's second law, the treatment of the gravitational measure of force has been altered, the proof of the lens equation has been simplified and new sections dealing with alternating current have been written. To satisfy a demand from many sources, the author has added 345 problems without answers, corresponding to analogous problems with answers in the original and present editions.

A survey of physics. Third edition. FREDERICK A. SAUNDERS, Professor of Physics, Emeritus, Harvard University. 736 p., illustrated, 14×22 cm. *Holt*, $4. Having appeared first in 1930 and in revised form in 1936 [Am. J. Phys. **4**, 146 (1936)], this well-known textbook for the general course has now been brought out in a third edition. The positions of the chapters on force and on statics have been interchanged, "thus shortening the painful period in which one has to assume that the student knows what he means when he speaks of a 10-lb weight, before he has studied Newton's laws." The chapter dealing with the gas laws has also been moved ahead of that on kinetic theory. A new set of problems has been furnished, most of them by E. M. PURCELL. Many other alterations and additions of a more minor character are in evidence.

HISTORY AND BIOGRAPHY

Torch and crucible—the life and death of Antoine Lavoisier. SIDNEY J. FRENCH, Professor of Chemistry, Colgate University, 297 p., 15×23 cm. *Princeton Univ. Press*, $3.50. In this skilfully written and beautifully printed biography, PROFESSOR FRENCH gives a vivid, nontechnical account of both the scientific and extra-scientific activities of the great and versatile LAVOISIER (1743–1794), founder of modern chemistry, leading man of affairs in France and an intimate of some of the greatest figures of the eighteenth century. The author takes the position that while LAVOISIER used the discoveries of BLACK, PRIESTLEY, CAVENDISH and others—discoveries that unquestionably made possible the completion of his dream of a revolution in science—nevertheless, modern findings deny that he got the germ of his great theory from them; "these findings should destroy the last shred of suspicion that Lavoisier's dream . . . originated anywhere but in his own head." This same head was later to fall on the guillotine, during the French Revolution. "It took only a moment to sever that head," said LAGRANGE, "but France will not produce another like it in a century." PROFESSOR FRENCH points out that the Revolution did not renounce science; "it merely failed to distinguish Lavoisier, the farmer, from Lavoisier, the scientist; it could not convict the one without the other, save the one without the other."

Roemer and the first determination of the velocity of light. I. BERNARD COHEN, Department of Physics, Harvard University. 63 p., 3 fig., 15×23 cm. *Burndy Library* (107 Eastern Blvd., New York), paper covers, 50 cts. This monograph is the first publication of a new series devoted to outstanding scientific discoveries and issued by the Burndy Library, a nonprofit organization founded to encourage interest in the history of science. MR. COHEN's study of OLE ROEMER appeared originally in an issue of *Isis* published in Belgium after the German invasion and hence not generally available to American readers. The study opens with a review of early ideas of a finite velocity of light and then takes up the immediate background of ROEMER's discovery, his determination of the velocity of

light and his accomplishments after returning from Paris to Denmark in 1681. In this last period, in addition to numerous scientific and civic activities in themselves "sufficient to fill a lifetime well spent," he "made fully as many observations as the great TYCHO, and designed and constructed astronomical instruments so efficient and so far ahead of his day, that he must certainly be rated as one of the greatest practical astronomers of all time." One of the leading figures of his age, he is today known generally only because of his discovery of "mora luminis" and for the first determination of the velocity of light.

Forthcoming publications announced for The Burndy Library series are the first translations into English of GALVANI's *De Viribus Electricitatis in Motu Musculari* and of KEPLER's *De Stella Nova;* and a three-volume limited edition of COPERNICUS' *De Revolutionibus Orbium Coelestium,* which will contain, on facing pages, the original Latin text and an English translation by EDWARD ROSEN.

PRE-INDUCTION AND SECONDARY SCHOOL COURSES

Laboratory manual in radio. LT. FRANCIS E. ALMSTEAD, KIRKE E. DAVIS AND GEORGE K. STONE. 146 p., 51 fig., 15×23 cm. *McGraw-Hill*, paper covers, 80 cts. Adapted for use with any of the more elementary textbooks in radio, the 36 experiments in this manual adequately cover both fundamental principles and types of exercises designed to develop manual dexterity and facility of manipulation. The equipment needed is simple; much of it can be obtained from old receivers. Although the instructions for each experiment are quite brief, incorporating little or no discussion of the underlying theory, they are to the point and are embellished with good wiring diagrams.

Fundamentals of machines. JOHN A. CLARK, FREDERICK RUSSEL GORTON, FRANCIS W. SEARS AND MAJOR FRANCIS C. CROTTY. 311 p., 300 fig., 15×22 cm. *Houghton Mifflin*, $1.24. The outline of the official pre-induction training course in machines is followed topic by topic in this clearly written and attractively illustrated textbook on machines and their underlying mechanical and thermal principles. The book is divided into 14 "units," and these in turn into shorter sections, or "problems," 58 in all. Many simple experiments are suggested that call for little equipment. Self-tests of the completion type and lists of questions accompany most of the units.

Wiley pre-service series. 14×22 cm. *Wiley*. These textbooks were prepared at the request of the War Department and the U. S. Office of Education in conformance with the official outlines for pre-induction training in secondary schools. Each book is planned to give a foundation for further specialization and for easier acquirement of skills related to specific military tasks. Applications drawn from military sources are stressed. The treatments are quite solid in character, but are much more than mere outlines and are prepared with regard for student interest and aptitude. The typography and illustrations are good.

Pre-service course in shop practice. WILLIAM J. KENNEDY, Instructor in Machine Shop Practice, Straubenmüller Textile High School, New York City. 342 p., 329 figs. $1.52. The opening chapters group tools in two classes—hand tools and machine tools—and help the reader to recognize and learn the use of such equipment. Subsequent chapters treat some of these shop tools and methods in greater detail, and then take up tools and processes frequently used in the Army. The three final chapters deal with wiring, wire-splicing, ropes, splices, knots, blocks and rigging.

Pre-service course in electricity. WILLIAM C. SHEA, Instructor in Applied Science, Straubenmüller Textile High School, New York City. 282 p., 212 fig. $1.52. The 13 chapters of this book are planned to provide material for 90 teaching periods on the simple elements of electricity, including the topics regarded as prerequisite for beginning work on communications, aviation and motorized equipment. The last four chapters deal with induced emf, motors, mutual and self-induction, and rectification of current. There are numerous worked problems.

Pre-service course in automotive mechanics. JAMES V. FROST, Instructor in Automotive Trades, Brooklyn High School of Automotive Trades, Brooklyn, N. Y. 551 p., 352 fig. $1.96. This full year course is planned to give the student a working knowledge of the construction and operating principles of all types of Army vehicles. The names, locations, operating principles and maintenance of the various units of an automotive vehicle are discussed at considerable length. Simple physical and chemical principles basic to the functioning of the automobile are outlined. Many excellent diagrams are included.

A comprehensive *Teacher's Manual* for each textbook is in preparation and will be available shortly.

MATHEMATICS

Odd numbers, or arithmetic revisited. HERBERT MCKAY. 215 p., illustrated, 13×19 cm. *Cambridge University Press* and *Macmillan*, $2. An American edition of an interesting little book for laymen. [*See* Am. J. Phys. **9**, 252 (1941).]

TABLES AND DICTIONARIES

A-c calculation charts. R. LORENZEN. 19 p., 146 plates, 24×32 cm. *Rider*, $7.50. Alternating-current circuit calculations can be made with a speed hitherto unattainable by means of this comprehensive series of charts and the supplementary scales that accompany them. The first two charts serve as an index for determining the subsequent chart to be used in making a given computation. The next 72 charts are used to compute reactance or impedance, and the final 72 are employed for susceptance or admittance. These charts are arranged in groups of nine, each group having the same frequency range but with ascending values of reactance or susceptance. Scales appear below the charts that serve the same purpose as a slide rule, namely, to compute squares, square roots and reciprocals. In other words, the present series of charts and scales combines the advantages of previously available reactance charts and slide rules, but are more precise than the older charts and speedier than the rules. The charts are printed in two colors to facilitate the location of points on them.

New commercial technical dictionary, English-Spanish. ANTONIO PEROL GUERRERO. 609 p., 16×24 cm. *Chemical*

Publishing Co., $10. More than 50,000 physical, engineering and commercial terms are listed in this Spanish-English and English-Spanish dictionary. Conversion tables for numerous units are also included. The author points out that La Academia de la Lengua, which is the only authority that determines the standards of the Spanish language, necessarily must act very slowly, for it accepts a new word only after thorough study and consideration. However, the United States through its industrial and commercial activities in Pan-American countries is exerting a tremendous influence on the Spanish language, for English words having no Spanish equivalents are rapidly being adopted bodily for most technical terms. Because of wide geographic distances, each of the 21 Republics inevitably chooses its own pronunciation for these adopted words, thus leading to confusion and misunderstanding. To set a standard of terminology for all technical and commercial words is one of the purposes of this dictionary.

Dictionary of science and technology in English-French-German-Spanish. MAXIM NEWMARK, Department of Modern Languages, Brooklyn Technical High School. 394 p., 15×23 cm. *Philosophical Library* (15 East 40th Street, New York), $6. In the first 200 pages of this useful, practical dictionary are listed some 10,000 current English terms, each with its French, German and Spanish equivalents. The words listed are those most frequently used today in the physical sciences and mathematics, and also in such applications as aeronautics, architecture, machine shop practice, meteorology, photography and radio. Each English entry is numbered and, in subsequent pages, there are separate indexes of the French, German and Spanish terms, correspondingly numbered, thus permitting two-way use of any of these languages with the English. Finally, there are several pages of conversion tables and brief lists of technical abbreviations for each language—the one for English, however, being neither very comprehensive nor in line with best modern usage. This dictionary should prove to be exceedingly useful, particularly for handy reference purposes; the library of every scientific and technical department should have a copy available.

RECENT MEETINGS

SPRING MEETING OF THE NEW ENGLAND SECTION OF THE AMERICAN PHYSICAL SOCIETY

THE twenty-first regular meeting of the New England Section of the American Physical Society was held at Wellesley College, Wellesley, Massachusetts, on April 3, 1943. Forty-six members were in attendance. The invited papers were as follows:

The mks system of units. WENDELL H. FURRY, *Harvard University.*

Physics at Wellesley College. LOUISE S. MCDOWELL, *Wellesley College.*

"Automatic volume control" of the ear. HAROLD P. KNAUSS, *Ohio State University.*

Entropy and probability. K. K. DARROW, *Bell Telephone Laboratories.*

Of the five contributed papers on the program, two pertained to instruction, as follows:

1. How the theory of relativity is taught to undergraduates at Worcester Polytechnic Institute. MORTON MASIUS, *Worcester Polytechnic Institute.*—An outline was presented of a course on this subject that is given at Worcester.

2. How to teach the theory of relativity to undergraduates. PHILLIP FRANK, *Harvard University.* (By title.)—The teaching of relativity to undergraduates has to be done in a way that not only will introduce them to a field of physics but also contribute as much as possible to their general education. Three pitfalls in particular have to be avoided by the teacher. He must not produce the impression that relativity (1) is a branch of mathematics, (2) is vague "philosophy" and not a science, (3) lacks meaning outside of physics and lacks general philosophic importance. The last fault is committed frequently by the best teachers who try to avoid by all means superficial popularization. But these teachers dissatisfy the student and he will look for information elsewhere, perhaps from scientific "quacks." Therefore, the only satisfactory method is to take the obstacle by a frontal attack and to attempt to avoid simultaneously all three faults. This can be done, (i) by avoiding every mathematical argument that is not indispensable, and by making it clear that by no mathematical argument can a theorem in physics be proved; (ii) by emphasizing that the theory of relativity starts from hypotheses about physical facts and proceeds by deriving mathematically from these hypotheses particular physical facts which are more accessible to experiment than the principles themselves; (iii) by pointing out that the new facts thus derived are more complex than the facts derived from traditional physics. Since the language of this traditional physics is therefore not very practicable for expressing the profusion of new facts, Einstein suggested the introduction of a new language, new syntactical rules, new definitions into physics which are more fitted to cover

the new facts. But this means the abandonment of the way of speaking which we use to describe the facts of our everyday experience. This change of the traditional pattern of description is of general interest outside physics proper. If it is made understandable to the student, he will grasp the role of relativity in philosophy. We can work out a simple scheme by which the physical meaning of the general hypotheses as well as the changes in the language of physics can be brought home to students in the junior year and even earlier.

The abstracts of the remaining papers will be published in a forthcoming issue of *The Physical Review.*

MILDRED ALLEN, *Secretary-Treasurer*

ANNUAL MEETING OF THE SOUTHEASTERN SECTION OF THE AMERICAL PHYSICAL SOCIETY

THE ninth annual meeting of the Southeastern Section of the American Physical Society was held at the Alabama Polytechnic Institute, Auburn, Alabama, on April 2 and 3, 1943. Approximately 65 members and guests were in attendance. Local arrangements were made by a committee headed by Fred Allison.

The regular program consisted of eight papers, abstracts for three of which are appended hereto. Abstracts of other papers will be published in a forthcoming issue of *The Physical Review.* Additional features of the program were a talk by M. H. Trytten on "The Manpower Situation in the Profession of Physics" and a panel discussion on "Physics and the War Emergency," led by A. E. Ruark.

At the business meeting the election of the following officers for the year 1943–44 was announced: *Chairman,* C. W. Edwards; *Vice Chairman,* R. C. L. Mooney; *Secretary,* E. Scott Barr; *Treasurer,* C. B. Crawley; *New Member of the Executive Committee,* K. L. Hertel.

The invitation extended by the University of Tennessee to hold the 1944 meeting of the section in Knoxville, Tennessee, was accepted.

CONTRIBUTED PAPERS

1. Industrial instruments. PHILIP EWALD, *Tennessee Valley Authority.*—Instruments may be grouped into scientific and industrial types. The chief value of scientific instruments lies in the ability of the user. Industrial instruments, which must be designed for the layman's use, may be subgrouped as indicators, recorders and controllers. The study of industrial instruments should follow a prerequisite system to include all types in the following order: linear and mass measurements, time, pressure, flow, electricity, temperature, remote control, automatic control, analyzers. This order is based upon present-day design of instruments. Automatic control systems may have the action of their component parts represented mathematically; the over-all action may be represented as a vibrating system with damping. A *p*H control system was described and the equations of action of the component parts given.

2. The place of Galileo's falling body experiment in classical dynamics. W. L. KENNON, *University of Mississippi.*—It was shown that Galileo's falling body experiment provides the only operational procedure for proving fundamentally the validity of Newton's laws of motion. The fact that two bodies of unequal masses when simultaneously released from rest fall together provides for the formulation of two simultaneous equations between the four quantities—time, distance, mass and force—in terms of which the motion is described by Newton's laws. Since the times and distances are equal there remain two unknowns—mass and force. The solution of the two simultaneous equations involving these unknowns shows that the forces are proportional to the masses. If the masses are made equal, it follows that the forces acting are proportional to the accelerations; this is our assurance of the validity of the Second Law. When distances are set equal, the times are equal; this is our assurance of the validity of the First Law and also provides the fundamental operation for measuring time. Galileo's experiment is thus established as the most significant and fundamental experiment in classical dynamics.

3. Teaching technics to physics students. DANIEL S. ELLIOTT, *Tulane University.*—Many advanced students in physics show a lack of manual dexterity and an inability to present results of research in a competent oral and written form. It is the opinion of the author that, in addition to an adequate vocabulary of physical terminology and a reasonable familiarity with modern and classical physical apparatus, the training of the student in physics should also include the elements of craftsmanship. This paper outlined some of the technics, mental and manual, which the student in physics is expected to acquire, together with the method of presenting these technics to graduates and competent seniors who are majoring in physics at Tulane University.

E. SCOTT BARR, *Secretary*

OREGON CHAPTER OF THE ASSOCIATION

THE Oregon Chapter of the American Association of Physics Teachers held meetings at Willamette University on November 21, 1942 and at Reed College on April 3, 1943. W. R. Varner, President of the Chapter, presided at both meetings.

Meeting at Willamette University

The program of papers was as follows:

Extension training and ESMWT physics and radio courses. H. R. VINYARD, *Oregon State College.*

Some experiments in precise electric measurements. JOHN POWELL, *Reed College.*

Supersonics. F. B. MORGAN, *Oregon State College.*

Dim-out requirements. W. WENIGER, *Oregon State College.*

A look ahead. A. A. KNOWLTON, *Reed College.*

Affectometer (lie detector). J. C. KYLE, *Oregon State College.*

Improvements in laboratory apparatus. E. H. COLLINS, *University of Oregon.*

Our department during wartime—a symposium. E. T. BROWN, *Willamette College;* W. V. NORRIS, *University of Oregon;* R. G. BAILEY, *Eugene High School;* W. WENIGER, *Oregon State College;* A. A. KNOWLTON, *Reed College.*

Meeting at Reed College

The following program was presented:

The theory of resistivity. ERIC L. PETERSON, *University of Oregon.*

Application of the thermopile to the absorption spectra of mercury. ROBERT W. PRATHER, *Oregon State College.*

Beta-ray spectra. LYMAN WEBB, *University of Oregon.*

The fourth law of thermodynamics and the thermoelectric effect. R. M. LICHTENSTEIN, *Reed College.*

The Weston standard cell. D. S. DEDRICK, *University of Oregon.*

Power line carrier current. DON MCCAFFERTY, *University of Portland.*

Vocational training in the shipbuilding industry. HARRY L. MYERS, *Supervisor, War Production Training.*

Pre-meteorology training. A. A. KNOWLTON, *Reed College.*

Physics as a profession. W. WENIGER, *Oregon State College.*

College and high school teaching compared. RUTH PORTER, *Gray's Harbor Junior College.*

During a luncheon meeting the group was addressed by Godfrey Vassallo, of the University of Portland. The officers for 1943–44 are W. Weniger, *President,* and E. Hobart Collins, *Secretary.*

E. HOBART COLLINS, *Secretary*

Forthcoming Meetings of the Association

THREE regional meetings of the American Association of Physics Teachers to be held during June 1943 will feature both contributed papers and invited papers emphasizing professional and national problems arising out of the war effort:

Chicago, Illinois, June 18–20; jointly with the Physics Section of the Society for the Promotion of Engineering Education.

Oregon State College, Corvallis, Oregon, June 14–19, during the meeting of the Pacific Division, American Association for the Advancement of Science.

Pennsylvania State College, State College, Pennsylvania, June 18–19, concurrently with the meeting of the American Physical Society.

For a copy of the program for any of these meetings, address the Secretary of the Association, Professor C. J. Overbeck, Northwestern University, Evanston, Illinois.

Summer Session in Applied Mathematics at Brown University

FOR the third summer, Brown University in its program of Advanced Instruction and Research in Mechanics, offers instruction and research direction in a 12-weeks session beginning June 14, 1943. A dozen graduate courses of a variety of grades are offered, largely in subjects related to mechanics, such as *Elasticity, Fluid dynamics, Theory of flight* and *Partial differential equations;* but there is one comprehensive course in *Mathematics of ultra-high frequencies in radio,* which is particularly designed for persons who expect to engage in research in that field. The staff in residence consists of S. Bergman, L. Bers, L. N. Brillouin, W. Feller, G. E. Hay, W. Hurewicz, P. W. Ketchum, W. Prager and J. D. Tamarkin. In addition a dozen lectures each are scheduled for K. O. Friedrichs, R. E. von Mises and S. P. Timoshenko.

This program is supported by the U. S. Government, the Carnegie Corporation and the Rockefeller Foundation; tuition fees are remitted. Address inquiries to the Dean of the Graduate School, Brown University, Providence, Rhode Island.

DIGEST OF PERIODICAL LITERATURE

A Device to Assist in Height Measurements

In finding the extension of a material under load the device in Fig. 1 assists in eliminating the effect of parallax when the height of a line is to be determined by means of

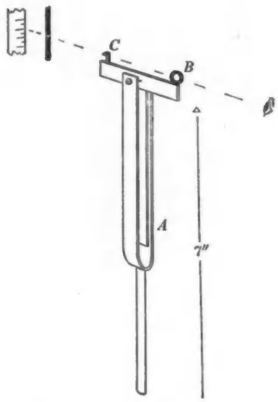

FIG. 1. A gravity-controlled sight.

a scale placed at a short distance in front of or behind the line. A **T**-piece is pivoted in a fork with a handle A. The rear sight B is a 4 B.A. brass washer, painted black and with a white line on its horizontal diameter. The front sight C is a short brass wedge, painted white. These sights are maintained in a horizontal line by the weight of the vertical arm of the **T**. The device is held in the hand, and the sights and the line of which the height is required are lined up on the scale.—S. L. ANDERSON, *J. Sci. Inst.* **19**, 186 (1942). D. R.

A Problem in Ballistics

If a projectile is aimed at a given point (x, y), *find the direction to which the two possible paths are equally inclined initially.* The problem is solved by first showing that the initial slopes $m_1[=\tan\alpha_1]$ and $m_2[=\tan\alpha_2]$ of the two paths are roots of the equation (for m),

$$x^2m^2-(2v_0^2x/g)m+x^2+2v_0^2y/g=0.$$

Use of the expressions for the sum and product of roots then yields

$$\tan(\alpha_1+\alpha_2)=-x/y=\cot(-\theta).$$

Therefore, $\alpha_1+\alpha_2=\theta+90°$, and the required direction-angle $\frac{1}{2}(\alpha_1+\alpha_2)$ is $\frac{1}{2}\theta+45°$.—P. BROCK, *Am. Math. Mo.* **50**, 64 (1943). D. R.

A Capillary Mercurial Barometer

The author many years ago made a capillary mercurial barometer that is simple, inexpensive and easily constructed; yet it is a far better instrument than many of conventional make and is unique in that it probably could be shipped by parcel post and be found to read correctly again without any further adjustment. The time needed for construction is about $\frac{1}{2}$ hr if the materials are ready.

Carefully wash and dry about 1 ft of rather thick-walled quilled-glass tubing, and then blow a 1-in. oblate bulb near one end (Fig. 1). Close to the bulb, heat about 1 in.

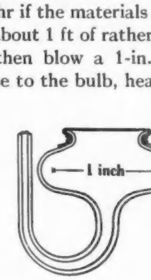

FIG. 1. Section of barometer bulb.

of the tubing until white and soft, and draw it out into a tube 40 or 50 in. long and 1 mm or less in bore. Break off the tube beyond the capillary part. Now make a sharp cut in the tube on the other side of and very near to the bulb, and apply a hot spot of melted glass at the end of the cut to cause the tube to break off here. Heat the lip of the bulb with a small blow-pipe flame until soft and, partly with the tang of a file and partly by spinning the bulb, fashion the opening to the form of a thistle funnel with a small but pronounced neck. *Immediately* heat the tapering tube close below the bulb in a batswing gas flame and bend into the form shown in Fig. 1. Let the glass cool to a temperature *not less than* that of some mercury—about $\frac{1}{4}$ lb, preferably vacuum distilled and already heated to dry it; then support the bulb and tube in an upright position on a strip of wood already prepared to receive it and pour in the hot mercury. Tie several thicknesses of fine linen over the thistle funnel to protect the mercury, and slowly tilt the mounting until it is nearly horizontal, watching the mercury gradually fill the tube but not enclosing any bubbles. When the mercury has reached the end of the tubing, direct a small blow-pipe flame onto the capillary a few inches from the end; the mercury will part and the glass will seal itself so that the loose end can be drawn off. Gradually raise the upper end until the tube is vertical; the mercury will fall nearly to its proper level. Any air that was adsorbed on the glass capillary will expand into the vacuum above the mercury; but if the tube is once more lowered to the horizontal this air will be swept up to the end of the capillary where a second sealing through the mercury will leave it trapped. The barometer is finally placed upright, the capillary sealed again about 33 in. above the bulb and the superfluous tube removed. A 3-in. length of millimeter or inch scale is then placed behind the capillary end so that the mercury reading upon it agrees with that of a standard barometer; thus the capillary depression is counteracted and the instrument is complete. If the cross section of the capillary is not more than 1/1000 of that of the bulb, the scale will not need adjustment.—C. V. BOYS, *J. Sci. Inst.* **19**, 168 (1942). D. R.

Units in Elementary Teaching

In elementary courses the limitations of time and the nature of the learning process impose certain requirements—restriction of the area to be covered, simplicity of approach, the attaching of new growth of understanding to the roots of the student's personal experience. These requirements indicate that in the elementary physics course the student should be expected to study only one system of units. For, if the student is to achieve clear understanding and an elementary competence in the applications of fundamental principles, he must not only learn names of units and some numbers that go with them; he must also study the theory of units and dimensions and their use in the laboratory and throughout the course. There is hardly time for the average sophomore to do all this for one system, let alone several. It need not be feared that the student will be unaware of other systems; he will learn to use them in later courses.

The single system to be chosen for study should combine simplicity with the possibility of application to experience; it should encompass electric quantities; and it should have a minimum of necessary conversion factors. These considerations point to the mks system as best adapted to the purpose, for the magnitudes of the meter, the kilogram and the second are readily perceivable, and conversion factors in this system are reduced to a minimum.

Understanding of other systems and competence in their use should be developed in later courses as a continuation in the student's mind from the concepts established in elementary physics. This requires a new plan of coordination of work in physics with that in engineering, where the courses should start with the concepts established in physics. It should be the business of physics in units, as elsewhere, to establish clear concepts and an elementary competence in their use. Understanding should take precedence over ground to be covered.—R. E. DOHERTY, *J. Eng. Ed.* **33**, 470–474 (1943). J. D. E.

Some British Views on Films as Teaching Aids

In a discussion of the use of films in physics instruction, held at a recent meeting of the Physical Society, it was pointed out that the present wide use of the film as a war training and propaganda medium may mark the beginning in Great Britain of a revolution in teaching and demonstration technics. Films may be used in the classroom in at least four ways: (1) as an illustration comparable in use to a lantern slide, as in the use of a loop film in the diagrammatical representation of cyclic actions; (2) as a basis for a film lesson, as when a particular film is shown, then fully discussed and finally shown again; (3) for review and revision purposes; a good 10-min film can effectively review the work of several lessons; (4) to show applications of physical principles and possibly their social implications, as in the use of industrial films, which often reveal more than actual field trips; "it is through the social and industrial documentary that science joins hands both with the rest of the curriculum and the outside world." A film should not be used in place of an available demonstration.

Each physical topic should be treated in the manner most suited to it. Obviously, an acoustics experiment should require a "sound" film. Similarly, a film about color should be in color. It thus follows that most expositional films should be "silent," whereas applications or background films, "sound." Generally speaking, a film that is to be run straight through should use sound, for then the commentary would be carefully worded and synchronized. On no account should a teaching film include irrelevant matter; it should be full of substance and devoid of theatrical packing.

Clearly the possibilities are great for films that depict the lives and work of great scientists. The few such films already available—for example, that on Pasteur—are obviously unsuitable for use as a whole. Excerpts might be made, but it would be much better to prepare special films that take into account the limitations imposed by classroom conditions.—ANON., *Nature* **150**, 691 (1942). D. R.

A Physiologist's View of Science Education and the Contemporary World

Society, as a whole and in its larger subordinate groups, is an organism or, better, an epiorganism, composed of men as its ultimate units just as a man is an organism composed of cells as units. The evolution of organisms is directed and fostered by their environment. As generations follow one another special organs appear and grow more sensitive; in short, a more complex organism comes into being. Social evolution likewise depends on environmental stimuli.

The frontiers of a social group were once geographic. Today, and even more tomorrow, they are of the mind or, better, of mind applied to the seemingly familiar world. The sense organs of the epiorganism are the scientists, those specialized units that become ever more sensitive to ever more stimuli and that barrage the social body ever more insistently with the excitations set up by these stimuli. Receptors in general are a sort of autocatalyst of evolution; scientists are autocatalysts of social evolution.

But the lay world is beginning to turn upon science. A crisis in the human spirit looms ahead, and science may face a dark age. Yet in principle science and democracy are kin. Democracy also depends on free exploration and discussion. In a genuine democracy the scientific habit of thought is absolutely essential. The present dangerous state is largely the mark of our failure, as teachers of science, to do our job properly. How can we expect citizens to act scientifically when they have never, even remotely, been exposed to (let alone dunked in) the scientific attitude?

Science in democracy has two educational duties: to impart some understanding of science to all citizens; to ensure social breadth for all scientists. Too frequently we fail to impart those mental attitudes of the practicing scientist that are so desperately needed if democracy is to flourish, if science is honestly to be applied to the problems of living together, if we are to have release from superstitious fear, tolerance for the new, intellectual honesty.

Scientists now have honored places at the council table of war; they should merit them at the councils of peace. But this means that they must qualify themselves to be more than scientific specialists; they must have a basic

general education as well as a superposed special one; they must take an active and informed interest in their society, not only as citizens but also as scientists. The trend, unfortunately, has been the other way. We do not, mostly, lead our students to see panoramas and understand relations. We are content when they can regurgitate facts. Perspectives are neglected. Learning is often rote and mostly passive. The teacher dogmatizes. The laboratory, which should serve to counteract just such defects, has, alas, become a particularly effective device for enhancing them. Our current science teaching does impart content; it does indicate some relationships and train in some skills; it sadly fails to develop the scientific attitude or to inculcate the habit of actively using it. In other words, our science teaching fails most completely in its one job that really matters to contemporary democratic society.

Our main duty to the great bulk of the students who take elementary science, and to our democratic way of living together (which really put the students into those classes), is to teach them to meet the problems of later life by the disciplined use of reason. This is to approach these problems with the attitude of the scientist toward his science and to tackle them with his method. The student must live science, not learn about it, in his formative years if he is to act scientifically later. To live science he must actively adventure on his own, must recognize and solve his own problems. And the laboratory is the boat that fares into this world of exploration, that excites yet restrains the imagination of its pilot.

We scientists have a tremendous responsibility. What we discover will continue to revolutionize the material ways of life. How we apply, and teach others to apply, our procedures and their yield can determine the spiritual ways of life as well. To instil the scientific attitude in the thoughts of men is our real job.—R. W. GERARD, *J. Chem. Ed.* **20**, 45–50 (1943). J. D. E.

Some Uses for the Slide Rule

Sum of two mutually perpendicular vectors.—This is equivalent to finding the angle A and hypotenuse c in a right triangle having known sides a and b. Let $a<b$. Then

$$\tan A = a/b, \quad 1+(b/a)^2=(c/a)^2.$$

Set a on the **C**-scale opposite b on **D**, and read angle A on the **T**-scale opposite the right-hand index of the **D**-scale. (On some rules this is found under a special hairline on the back side.) Without changing the setting, read $(b/a)^2$ on the **A**-scale opposite the left-hand index on **B**. Add 1 to this number to obtain $(c/a)^2$. Then move the slide to the right until the index on the **B**-scale is opposite $(c/a)^2$ on **A**, and read c on the **D**-scale opposite the known value a on **C**. Thus the vector sum is obtained completely from two settings of the rule.

Accurate determination of angles.—An acute angle θ can be determined more accurately from $\tan\theta$ or $\cot\theta$ than from $\sin\theta$ or $\cos\theta$, and more accurately from $\log\tan\theta$ or $\log\cot\theta$ than from $\log\sin\theta$ or $\log\cos\theta$. Moreover, angles are determined more accurately from the **T**-scale on a slide rule than from the **S**-scale. Thus, given $\cos\theta=12/13$, we may read on the **S**-scale that $90°-\theta$ is $67°\,30'$ and hence that θ is $22°\,30'$, with an uncertainty of $10'$. On the other hand, if we write $\tan^2\theta=(13/12)^2-1=25/144$, and set the right index of the **T**-scale opposite 14.4 on the **A**-scale, we find $\theta=22°\,37'$ on **T** opposite 2.5 on **A**, and θ is correct to within $1'$.

If θ is near 45°, it is best to determine it from $\cos 2\theta$. Thus, given $\sin\theta=21/29$, then $\cos 2\theta=1-2\sin^2\theta=-41/841$, or $\sin(2\theta-90°)=41/841$. Setting the right index of the **S**-scale opposite 84.1 on the **A**- or the **D**-scale, depending on the type of rule used, we read $2\theta-90°=2°\,48'$ on the **S**-scale opposite 4.1. Hence θ is $46°\,24'$, correct to within $10''$.

Other applications described by the author are (i) graphs of ellipses and hyperbolas, (ii) parabola in polar coordinates and (iii) solution of a cubic equation.—J. S. FRAME, *Am. Math. Mo.* **50**, 55–57 (1943). D. R.

Check List of Periodical Literature

Scientists at sixteen. B. Bliven, *Sch. and Soc.* **57**, 57–61 (1943). The editor of *The New Republic* gives a revealing account of activities and potentialities of the Science Clubs of America and of the Annual Science Talent Search. There are now about 2200 clubs with 60,000 members. "It is safe to say that any average individual among these 60,000 . . . knows far more about science than does the average well-educated adult who has never had the advantage of a Science Club membership."

An instrument for drawing confocal ellipses and hyperbolas. R. M. Sutton, *Am. Math. Mo.* **50**, 253–254 (1943). A convenient and flexible blackboard device.

A needle in a bowl. N. Miller and H. Eves, *Am. Math. Mo.* **50**, 262–263 (1943). The following problem is solved. In a smooth hemispherical bowl of radius a, a smooth needle of length $2l$ ($l<a$) is placed with one end projecting over the rim and is then released; show that the needle will come to rest in a horizontal position if l is less than $a(2/3)^{\frac{1}{2}}$.

Applications of physics to the heating and ventilation of buildings. A. F. Dufton, *Nature* **150**, 678–680 (1942). A simple survey.

Sir Joseph Larmor and modern mathematical physics. G. D. Birkhoff, *Science* **97**, 77–79 (1943).

Electron lenses. D. Gabor, *Nature* **150**, 650–652 (1942). A brief survey.

Physics in 1942. T. H. Osgood, *J. App. Phys.* **14**, 53–68 (1943). A survey of research.

A mechanical oscillator for recording compounded linear waves. A. D. Bulman, *J. Sci. Inst.* **20**, 10–12 (1943). This teaching device for demonstrating various wave phenomena provides a universal apparatus for combining oscillations both linearly and rectilinearly. From a wide range of possible experiments, those described are: recording a s.h.m. track; logarithmic damping; verification that period and amplitude are independent for small arcs; the beat effect; linear superposition of harmonics on a fundamental; the coupling effect; vibrations compounded rectilinearly.

Notes on high vacuum technic. G. Burrows, *J. Sci. Inst.* **20**, 21–28 (1943). Deals with topics of general interest that arise frequently in high vacuum work.

The American Institute of Physics—a report to physicists. H. A. Barton and G. H. Burnham, *Science* **97**, 172–176 (1943). Its background, organization and activities.